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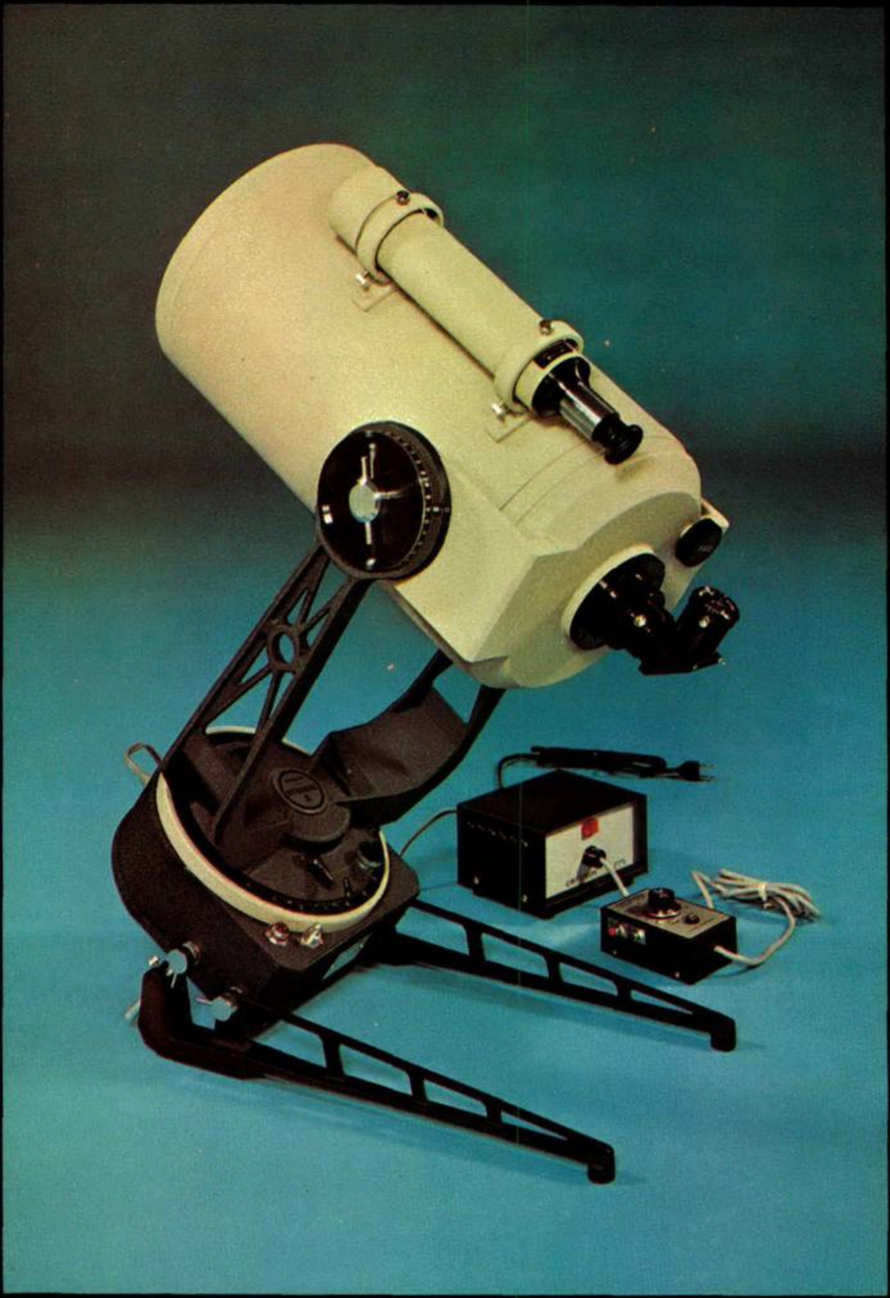

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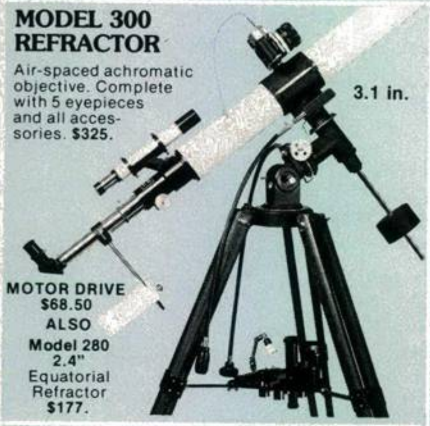

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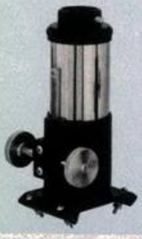

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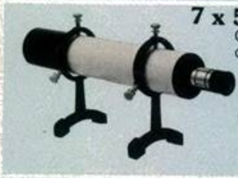

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Cover

Crescent Jupiter, glowing dull red from its own internal heat, dominates the sky over its newly formed satellite Io. In the distance, volcanic eruptions of steam and molten lava fountain above the landscape, blotting out Jupiter and stars. Eventually the molten rock cools and begins to form the crust of this most unique of all the Jovian satellites. Artwork by Victor Costanzo.

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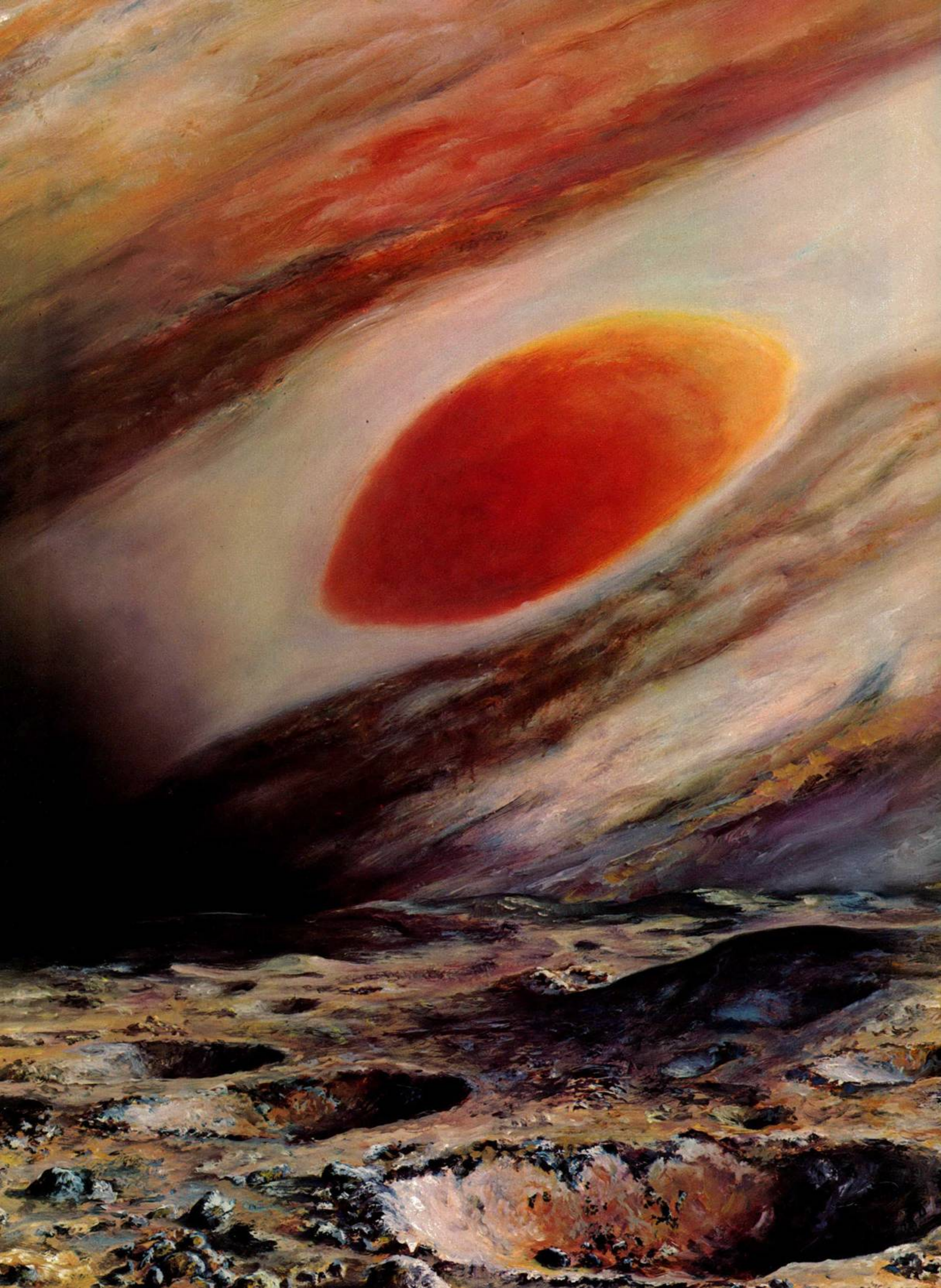
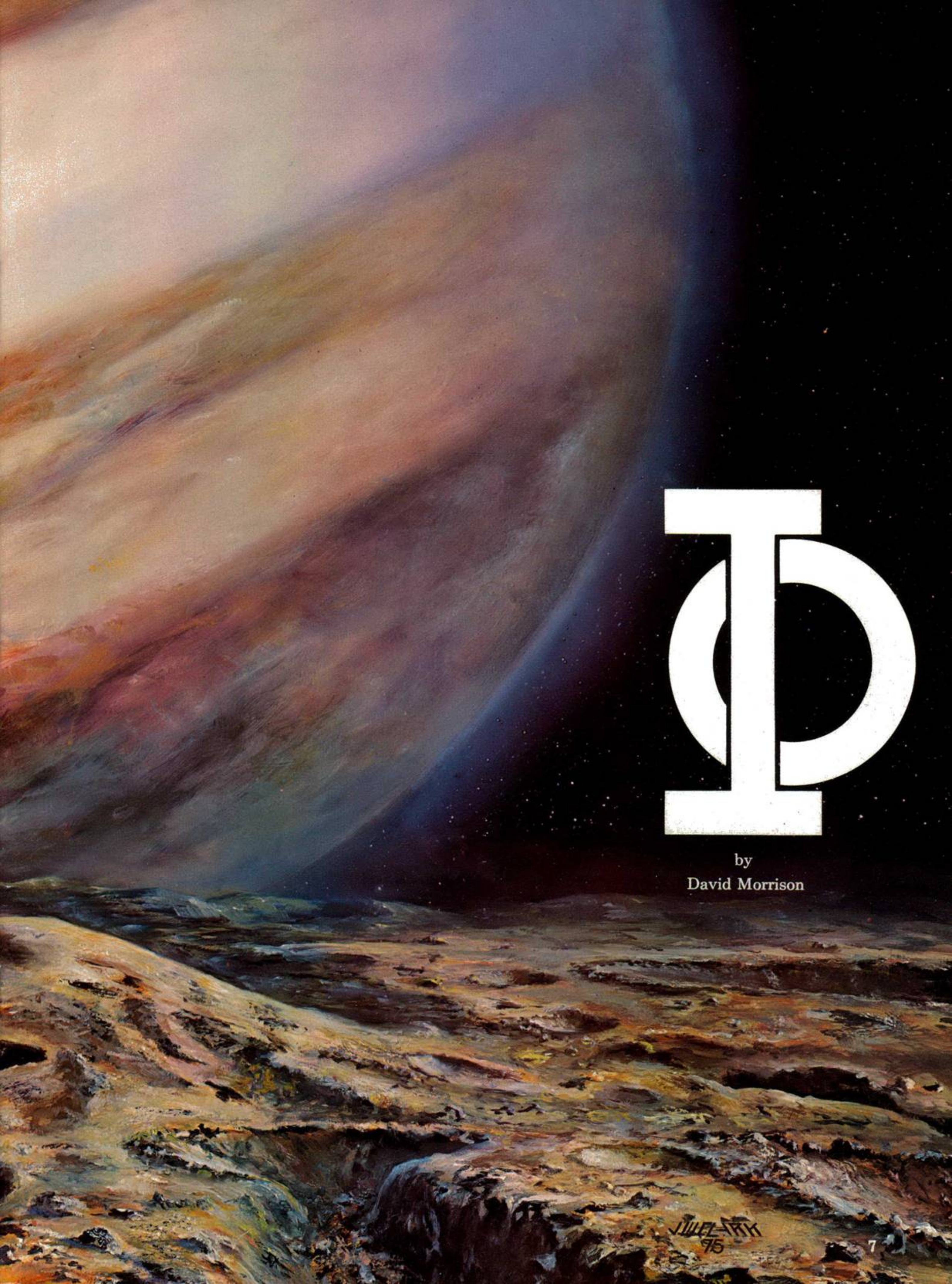
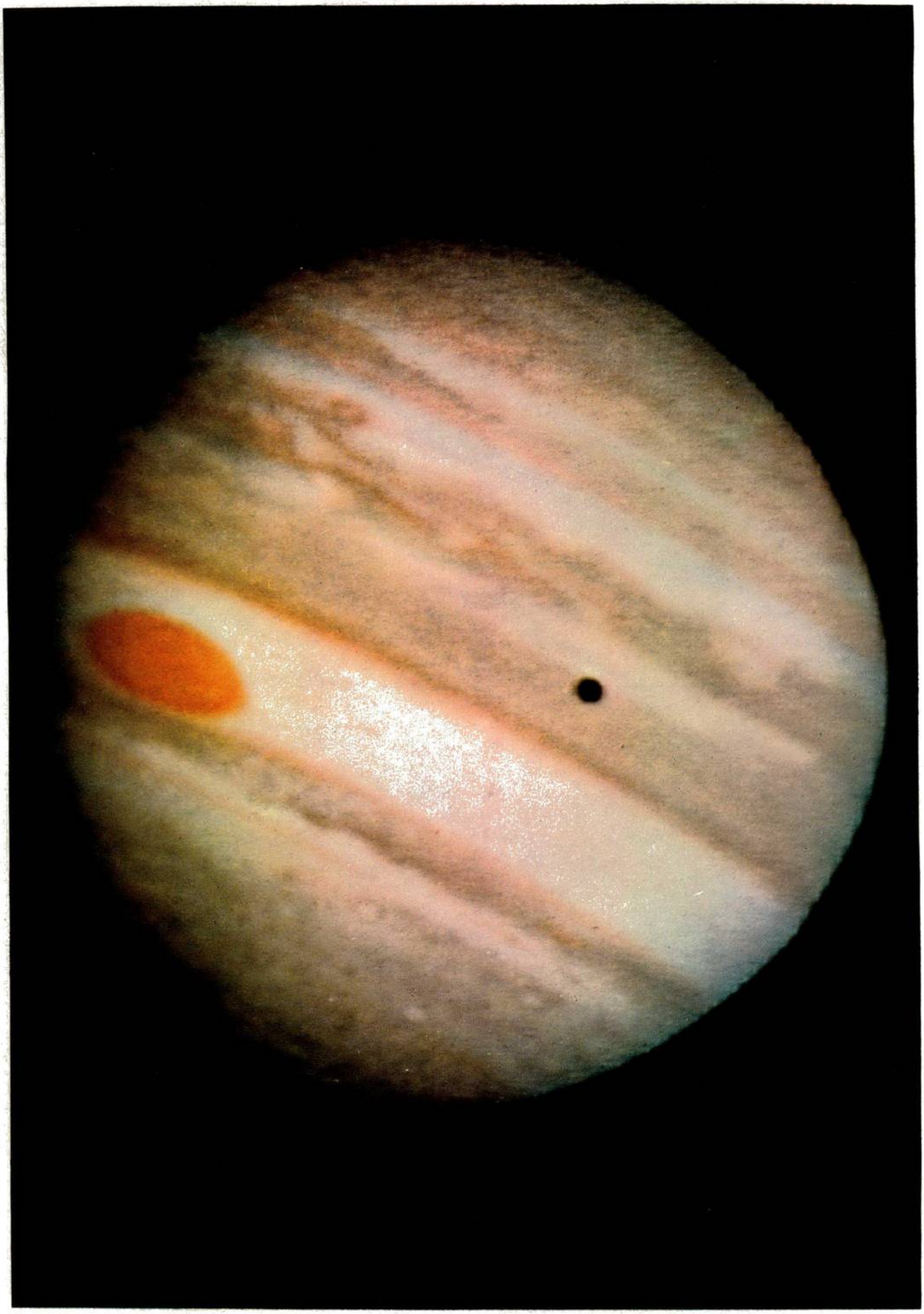




IO

by

David Morrison



If people ever set foot on Io, it will be from behind several inches of lead.

This frozen, airless world — as large as Mercury, but 500 million miles from the sun — would be inhospitable by any standards. But Io is particularly cursed.

Bathed in the heat of Jupiter at its formation, Io has never broken the bond with its giant neighbor which now wraps it in a deadly shroud of high energy radiation. Vast electric currents move between Jupiter and Io, and a continuous blast of electrons and protons strikes the satellite's surface.

Io is one of the four "Galilean" satellites of Jupiter (so-called after their discoverer); the others are Europa, Ganymede and Callisto. They are much larger than the other Jovian moons and their orbits are closer to the planet. They were one of the first discoveries of the telescopic era, and study of their motions was influential in developing Newton's theory of gravitation. But they fell into relative oblivion after the 18th century — being distant, difficult to see, and dwarfed by their primary. Only in the past few years have many scientists begun to appreciate that the Galilean satellites — along with Titan, which belongs to Saturn, and Neptune's Triton — are planetary bodies of respectable size, all as large as our moon.

But the satellites are not simply cooler carbon copies of the planets and moons nearer the sun. They must have had a radically different origin. Unlike the close-in planets which condensed from the gas and dust in the inner reaches of the protosolar nebula (where temperatures never dropped below the freezing point), the outer solar system was born in the chill of space. In addition, the satellites were greatly influenced by the giant planets about which they formed. These influences were particularly significant in molding Io, innermost of the Galileans.

For instance, the terrestrial planets (Mercury, Venus, Earth and Mars) are much denser than the outer satellites. With densitites ranging from 4.0 to 5.5 times that of water, they must be composed of heavy metals (primarily nickel and iron, which are cosmically abundant) in addition to the rocky minerals we find on their surfaces. In the outer solar system, though, the picture is different. Callisto and Ganymede have densities of less than 2.0 — and Titan is only 1.3 times as dense as water.

Such low densities indicate that these satellites contain little metal and must be composed of something lighter. The obvious material is water, since its components (hydrogen and oxygen) are among the most plentiful elements in the universe — and water is a particularly stable compound. There is some observational evidence for this: The spectroscope reveals that the rings of Saturn and the bright surfaces of Europa and Ganymede are composed of water ice. And, as noted a few years ago by John Lewis at MIT, this water may be mostly liquid (not frozen), making the satellites planet sized drops of water with cores of mud and crusts of ice.

But Io is a maverick. It also has a bright, highly reflective surface — but it's not made of ice. Infrared spectroscopy would tell us if it were. Even more remarkably, Io has the same density as the moon — about 3.5 times that of water. So neither its surface nor its interior can have very much water.

Where was Io when the ice was being passed out? Its sister satellites seem to have plenty of it. And if it did have ice once, where did it go?

To search for the answer, we must go back in time to the birth of the Jovian satellite system. Jupiter was just emerging from a shroud of spinning, collapsing gas and dust. The material that would become its satellites surrounded it in a dense disk.

The bulk of material in this protosatellite cloud was water. In the center, though, infalling material generated heat from gravitational energy. Temperatures at the center of the proto-Jupiter reached a peak of 145,000 degrees Fahrenheit, and the planet radiated 1/1,000 as much energy as the sun. This radiation would have kept the temperature above the condensation point of water for 5 to 10 million years. Io was probably formed during that interval, thus depriving it of the ice that was so plentiful elsewhere.

It's hard to say exactly how hot the infant satellite was. We don't know how much Io was heated by infalling material as it formed. If accretion was rapid enough, the interior could have become hot enough to melt rock — but more likely it ended its main period of growth at a few hundred degrees Fahrenheit. Jupiter would have heated it further, though, glowing dull red across 1/3 of the sky. And mighty tides from the giant planet would slow Io's initially rapid rate of spin, with the lost rotational energy turning into heat. Still more heat would be generated by radioactive decay of elements such as uranium and thorium. Over a few million years, this heat would build up until the melting point of some of the interior minerals was reached — which would

Caption for pages 6 & 7

Like a malevolent monster with a huge, unwinking red eye, the incredible bulk of Jupiter looms over the dusty surface of its satellite Io. Great salt beds coat the Ionian landscape like dried-up oceans, and craters similar to the moon's pockmark the ground. This amazing vista is one that mankind may never see firsthand, for Io — encased in Jupiter's magnetic field — is one of the most lethal places in the entire solar system. Artwork by John W. Clark.

Io's shadow crosses the cloud surface of Jupiter in this Pioneer 10 photograph taken in 1973. Of all Jupiter's large moons, Io is the closest to its primary, and it lies deep in the planet's radiation belts. The sodium cloud surrounding the satellite makes it a good conductor of electricity, causing huge electrical currents to flow between Io and Jupiter. NASA photograph.

mark the start of a new and important phase in the satellite's history.

As Io's interior melted, heavier materials began to sink toward the center, while lighter ones floated up toward the crust. Heat liberated water that had been chemically bound in the rocks, and hot liquid water percolated up toward the surface. The hot water dissolved minerals along the way, just as seeping ground water on Earth can dissolve limestone to form caves.

We can only guess how much water finally arrived at the surface of Io, or how rapidly it got there. Perhaps it was released slowly, seeping upward only to evaporate into space. Or maybe it escaped rapidly — through great volcanos and geysers, spraying hundreds of yards into the air. If temperatures were high enough, not only water but steam and even molten lava may have spewed out in vast eruptions.

If water was released from the interior more rapidly than it could have evaporated into space, Io might once have had great oceans of liquid water under thick, shifting packs of ice. These oceans would have been heavy with dissolved minerals from the interior — primarily salts made up of sodium, sulfur and chlorine.

But the source of water from the interior couldn't last, and eventually the oceans would dry up because of Io's low gravity and consequent low atmospheric pressure. To visualize what Io would look like after this had happened, we have only to ask ourselves what Earth would look like if its oceans dried up — the ocean basins would be filled with salt beds hundreds of yards deep. If that happened on Io (and subsequent geologic processes left the surface undisturbed), then Io may still have a coating of salts today. There's some experimental evidence that this is indeed the case.

Io has one of the most highly reflective surfaces of any planet or satellite — reflecting more than 60 percent of the sunlight striking it! The brightest parts of the moon reflect only 17 percent; the whitest rocks we know of, only 40 percent. As mentioned earlier, this led astronomers to believe that Io's surface was covered with ice — until infrared spectroscopy in 1972 showed it couldn't be.

Not only does the infrared spectroscope prove there's no (or very little) water or other ices on Io's surface, it also reveals a puzzling reflection property that makes Io unique in the solar system. Io has an equally high reflectivity in the infrared as it has in visible light. Very few substances reflect highly in both parts of the spectrum.

There's one natural reflecting surface on Earth that has this property: dried lake beds such as the flats surrounding the Great Salt Lake in Utah. In the laboratory, certain preparations of the element sulfur also have the right properties. And material from one other cosmic body passes the tests: salts from a well-known carbonaceous chondrite meteorite called the Orgueil meteorite — which has precisely the composition predicted by the evolutionary processes proposed for Io: a surface of salts (primarily sulfates) with possibly some elemental sulfur as well.

In spite of its high reflectivity, the surface of Io would not seem as bright to human observers as the salt flats of terrestrial deserts. Io is five times farther away from the sun, so the sunlight reaching its surface is only 1/25 as bright. Once you adjusted to the low level of illumination, a landscape on Io might resemble a desert on Earth. The colors would be similar, with the white salt stained by impurities to varying shades of yellow, orange and brown. Even through a small telescope, Io looks redder than Jupiter's other satellites. There's no way yet for us to predict exactly what the surface features of the satellite are — mountains, valleys, craters or whatever. We do know a few things, though.

We can be sure that whatever the composition of Io, the surface was influenced by the history of continuous collisions with small meteoric fragments — common to all objects in the solar system. Occasional impacts by large bodies must produce craters like those on the moon and Mercury, and the rain of finer cosmic dust is likely to fragment and stir up the surface on a smaller scale.

Io's surface must be dusty and porous, according to 1972 measurements of the thermal infrared emission from the satellite. Once in each orbit, Io passes through the shadow of Jupiter — cutting off sunlight for a couple of hours. Astronomers in Hawaii and California found during these eclipses that Io cooled very rapidly, and then reheated just as rapidly when it emerged into the sunlight. This is the way objects of low thermal conductivity behave, like commercial insulating material, or — more to the point — the surface of the moon. So the surface of Io is covered with loose, dusty material and not a clean, solid surface of rock.

Io's strange surface chemistry is not the only peculiar thing about it. Several years before the first infrared spectroscopy of the satellite, radio astronomers studying Jupiter made an amazing discovery. At wavelengths of tens of meters, Jupiter sent bursts of static at irregular intervals. Eventually they found a sort of pattern: Most of the noise storms occurred when one of two or three Jovian longitudes pointed toward Earth — but *not every* time.

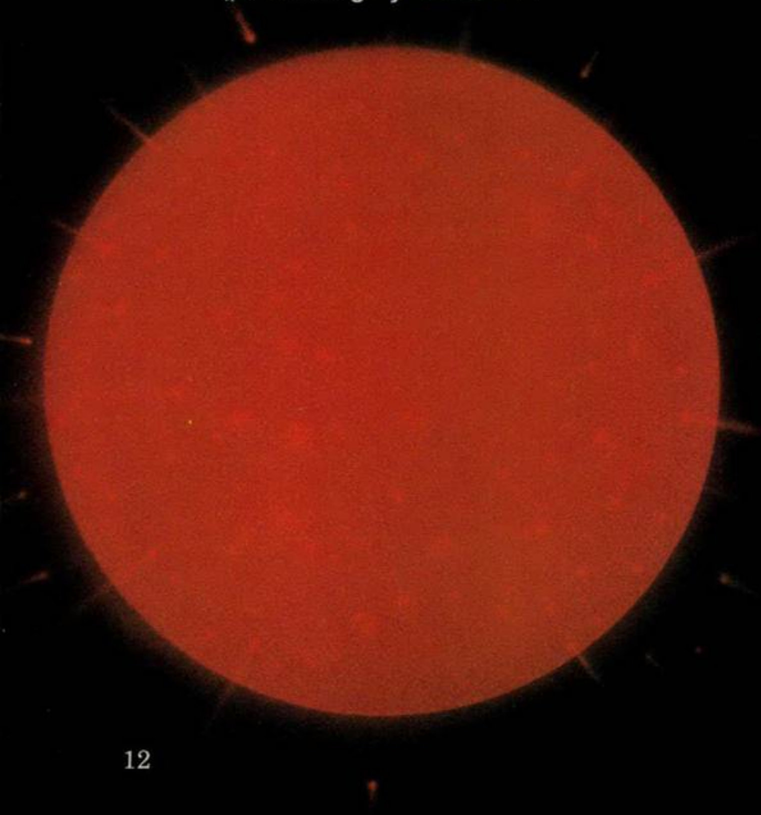
Then someone noticed that the emission came and went in intervals of about 21 hours. This period

The distant sun lights up the surfaces of Jupiter and Io as a Mariner probe approaches the Jovian system, preparing for a close flyby of the satellite. Scheduled for launch in 1977, the spacecraft will photograph about half of Io's surface; this detailed coverage may remove some of the mystery now surrounding this tiny, bizarre world. Artwork by Adolf Schaller.

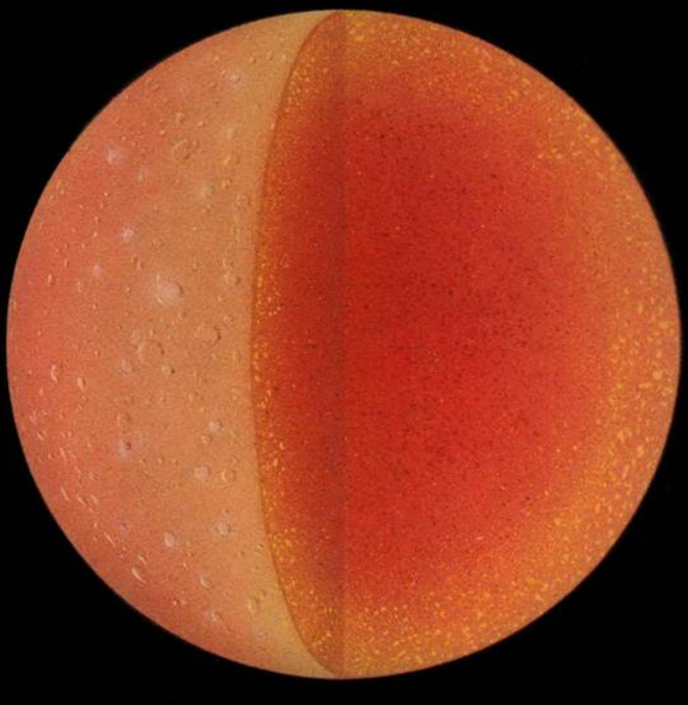
Evolution of Io

To discover why Io is unique in so many ways among Jupiter's satellites, we must travel back in time to investigate its origins. Io was born in the cloud of nebulous material that surrounded the recently formed Jupiter. Although this cloud was mainly composed of water, many factors combined to keep the water from condensing as Io formed — including heat generated by infalling material and energy radiated from the giant planet nearby. By the time Io had fully evolved, all the heat had been building up over a few million years until it reached the melting point of some of the minerals in Io's interior. Heavy materials began sinking toward the center of the satellite, while lighter ones floated up to the crust. Water that had been chemically bound in the rocks was freed by the heat and boiled to the surface, dissolving minerals along the way. If the water was released from inside Io more quickly than it evaporated into space, Io may have had oceans replete with dissolved minerals — mostly salts made of sodium, sulfur and chlorine. But eventually the interior source of the water gave out, and as the water evaporated, the oceans dried up — leaving behind all the salt they contain and giving Io its highly reflective surface. Thus Io is very different from the other Galilean satellites, which evolved at a greater distance from Jupiter and retained the water in their ice-covered surfaces. Artwork by Victor Costanzo.

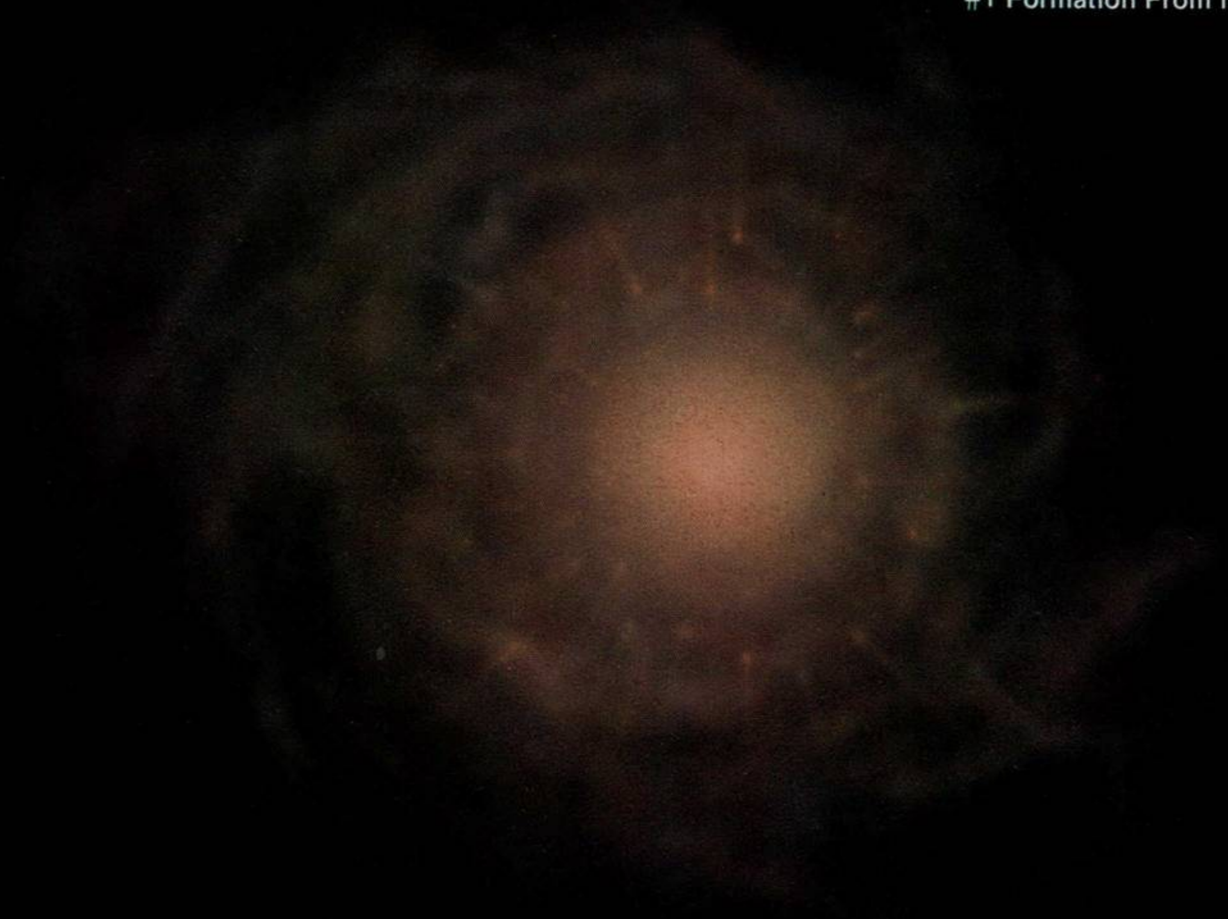
#2 Heating by Accretion



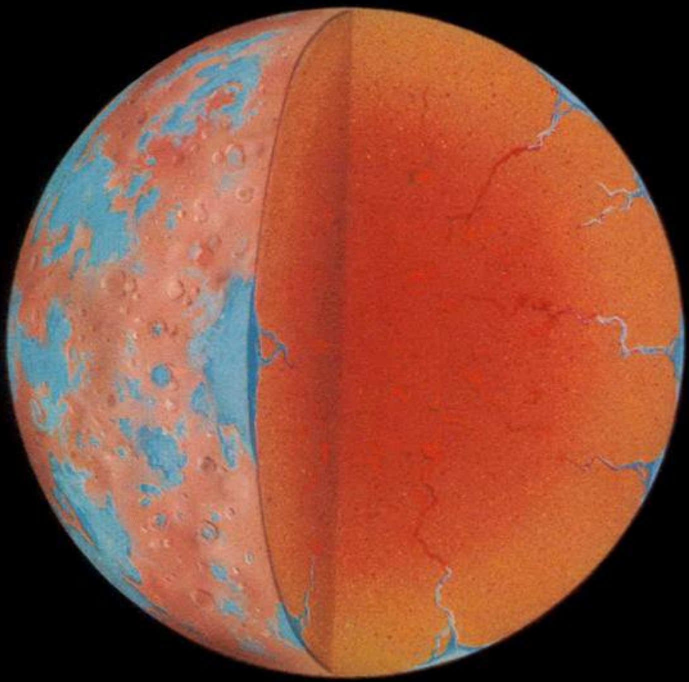
#3 As Interior Melts, Differentiation Takes Place



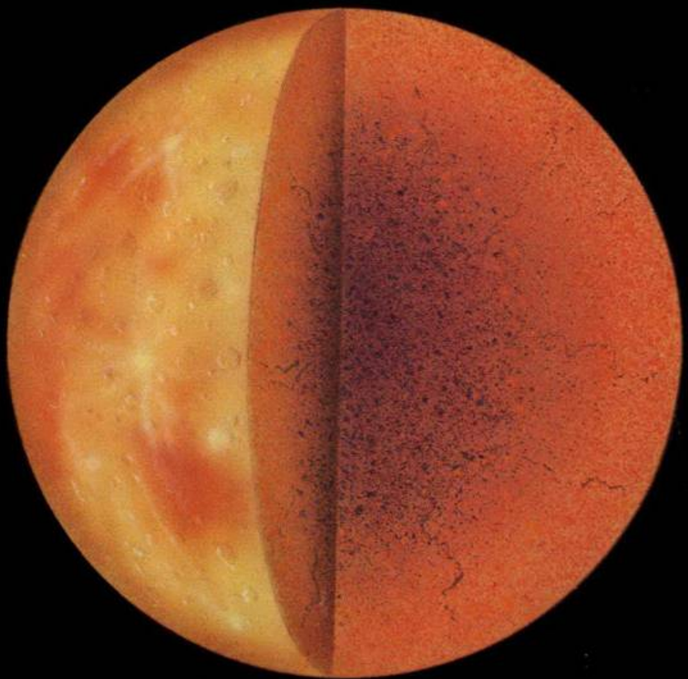
#1 Formation From Nebula

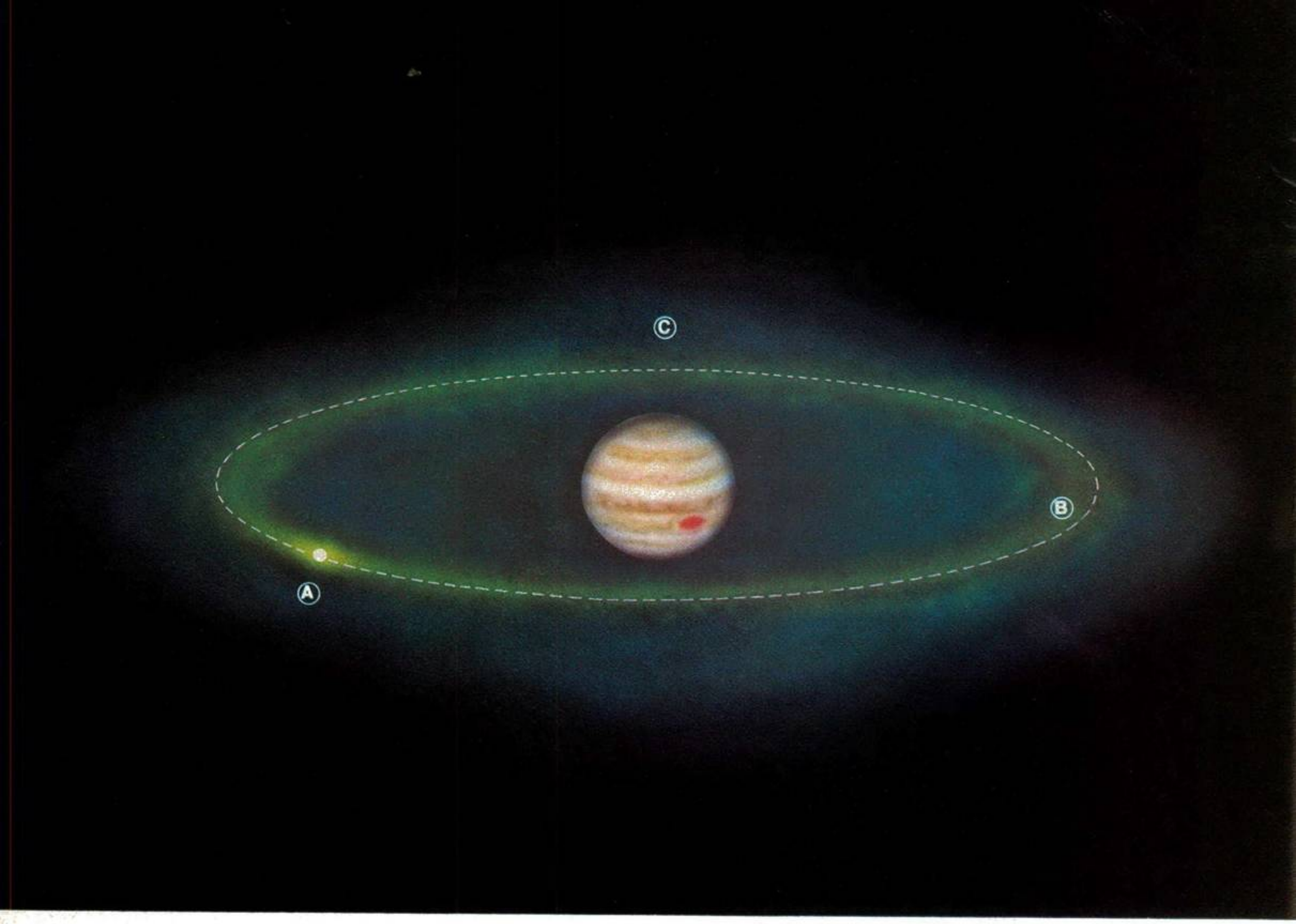


#4 Liquid Water Percolates to Surface



#5 Water Evaporates Leaving Salt Beds





The sodium "atmosphere" of Io is not limited to a small area around the satellite, although its greatest concentration (A) is near Io. A great cloud of sodium is distributed (B) all along the orbital plane, while a much more tenuous cloud (C) extends even farther — over Jupiter's poles. The cloud is constantly replenished by Io's salt surface, as high energy particles from Jupiter's radiation belts chip off the sodium atoms and release them into space. Artwork by Victor Costanzo.

of time has nothing to do with the rotation of Jupiter — but it's exactly half the orbital period of Io!

Once they saw this totally unexpected relationship, it didn't take long to figure out that the noise storms happened only when Io was on one side or the other of Jupiter.

So it was no wonder that the bursts seemed erratic to early investigators. Both conditions had to be fulfilled simultaneously — Jupiter facing the right way and Io being in the right part of its orbit, as seen from Earth.

No effect like this had ever been observed before. What made it even more mysterious was that the bursts came from Jupiter's atmosphere — not the Van Allen type belts that surround the planet. So either Io was influencing Jupiter's atmosphere directly or was in some way "beaming" the radio signals toward Earth. Theoretically, such beaming could take place only if giant electrical currents flowed between Io and Jupiter — but that meant that Io had to be a good conductor of electricity. Rocks aren't.

The mystery deepened in 1973, when routine spectra were taken of the Jovian satellites (from Harvard). Io, or the region around it, was glowing with the characteristic radiation of sodium gas. None of Jupiter's other satellites showed this emission.

For Io to have any atmosphere at all is strange. Its surface gravity, like the moon's, is too low to hold onto any tangible amount of gas for very long. And an atmosphere of metal-like sodium — that's even more weird.

Jet Propulsion Laboratory observations soon showed that the sodium was glowing by scattered sunlight rather than as a result of auroral activity or high temperature. To an observer on Io, the light would be very bright — like terrestrial aurorae in high latitudes. Unlike our aurorae, though, Io's sodium glow wouldn't show delicate structure, but would just suffuse the entire sky with a uniform pale yellow light. You wouldn't see it in the daytime because of the sun's competition, but at night it would be bright enough to blot out fainter stars. Only during eclipse, when Io and its surrounding cloud pass through the shadow of Jupiter, would the yellow glow fade away to reveal the stars in their full glory.

Then investigators at the University of Texas found that the sodium emission wasn't confined to a small area around the satellite, and in fact wasn't an atmosphere at all in the usual sense. Instead, there's a vast region of glowing sodium gas extending in a great doughnut shaped cloud all around the orbit of Io.

But what could be the source of such a cloud? It has to be continually replaced from the surface of Io, or it would simply dissipate into space.

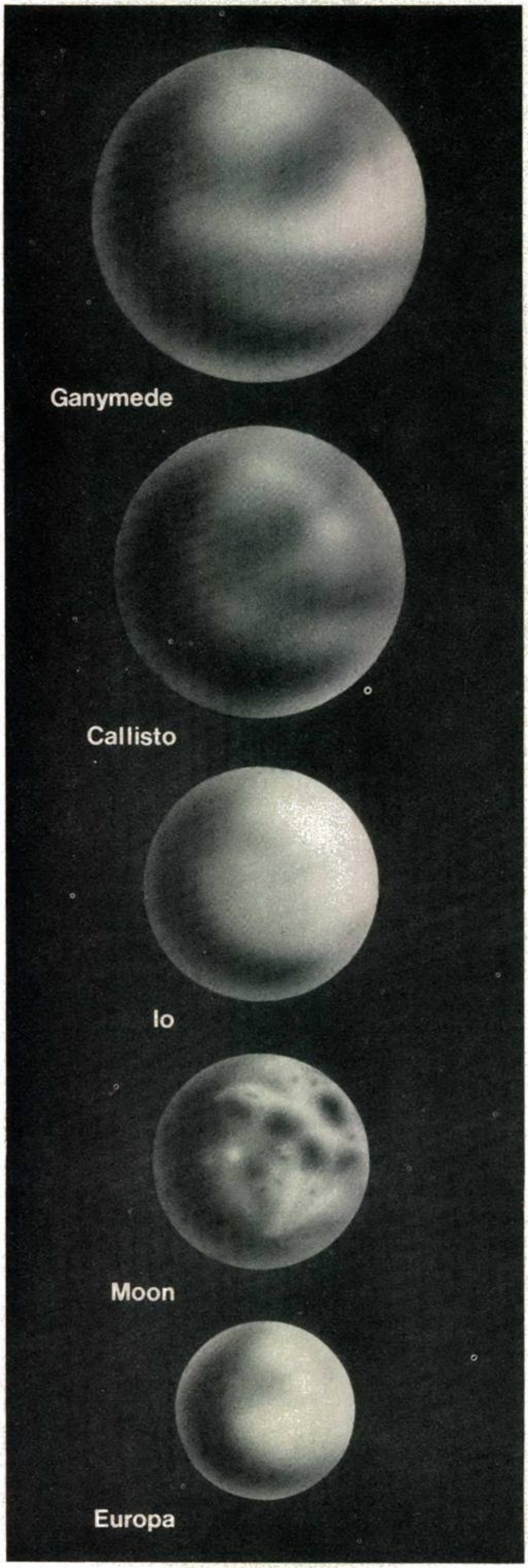
From the size of the cloud, you can calculate how fast the surface of Io has to supply the cloud with sodium atoms. It comes to 100 million atoms per second, for each square inch of surface.

Scientists in the JPL group studying Io believe that such large amounts of sodium might be released by "sputtering". This is what happens when high energy protons or electrons strike a solid surface, chipping off atoms to release them into space. The high energy particles come from Jupiter's Van Allen type belts, and the sodium could be accounted for by the salt and sulfur model provided for Io's surface.

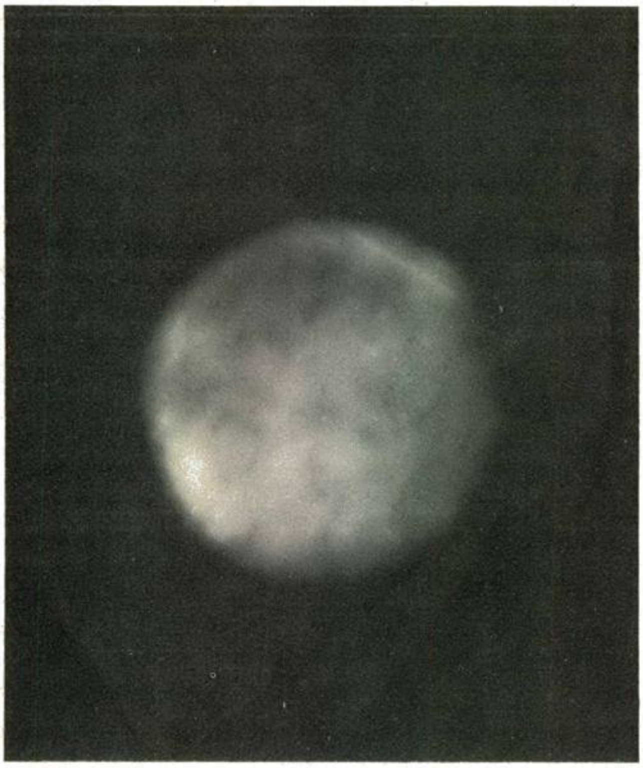
Jupiter's Van Allen belts were discovered more than a decade ago, from synchrotron radiation emitted by electrons spiraling within Jupiter's magnetic field. The first direct measurements weren't made until Pioneer 10 passed Jupiter in December 1973. When it crossed the orbit of Io, the spacecraft was being hit by more than a billion high energy particles per second, for every square inch of surface. The on-board computer issued erratic and unprogrammed commands, because of the high radiation. By the time Pioneer 10 passed closest to Jupiter — only 81,000 miles above its turbulent clouds — several experiments had been zapped with more than 90 percent of their maximum rated radiation exposure. This is the environment Io lives in.

Europa and Ganymede are affected by this steady stream of radiation, although far less than Io. As Pioneer crossed the orbits of these two satellites, it found decreases in electron intensity where those moons had swept out and absorbed a certain fraction of those particles.

But near the orbit of Io, the situation was much more complex. Some particles were depleted near the orbit — but others were accelerated by the satellite to even higher than normal energies. It almost seemed as if Io were fighting back against Jupiter's radiation bath. On the sides facing toward and opposite Jupiter, great charges called plasma sheaths were built up, causing the particles' peculiar behavior. It has been guessed, also, that an electric



Unlike its sister satellites in Jupiter's family, Io's highly reflective surface is not composed of water ice. Io also has a higher density than any of the other Jovian moons — 3.5 times that of water. This is the same density as our own moon, indicating that Io may be similar in more ways to the dense terrestrial bodies of the solar system than to its companion satellites. Artwork by Victor Costanzo.



This Pioneer 10 photograph of Ganymede is the best picture we currently have of any of the Jovian moons. Io has aroused more curiosity than Ganymede, but scientists will not know what Io looks like until the scheduled Mariner flyby later this decade. Mariner will provide much more detailed information than the above picture shows; high resolution photography should show features as small as a half mile across. NASA photograph.

current flowed between the planet and the satellite, which would explain Io's modulation of the Jovian radio emission. Evidence that this current exists was detected by Pioneer 11, which reached Jupiter a year after its predecessor.

Pioner 10 was carefully aimed so that it would pass behind Io (as seen from Earth) for a few seconds, temporarily blocking the spacecraft's signals. Just as the radio waves passed along the satellite's edge, their velocity increased a precisely measured amount. This could only be caused by passage through an electrically conducting medium — an ionosphere.

Like Earth, Venus, Mars and Jupiter itself, Io is surrounded by a sphere of ionized gas — extending to about 600 miles above its surface. Since an ionosphere is produced by sunlight stripping electrons from the atoms in a neutral atmosphere, its presence around the satellite implies the existence of such an atmosphere — an extremely tenuous one — near Io's surface.

Another instrument aboard both Pioneers was a small telescope sensitive to the far ultraviolet light radiated by atomic hydrogen. This telescope detected a strong emission from the thin Ionian atmosphere, showing that it contained hydrogen as well as the sodium which had already been found. In fact, another emission seemed to originate in a torus shaped cloud surrounding Io's orbit (similar to the sodium cloud previously discovered). This second cloud also has its source on the satellite's surface — but about 1,000 atoms of hydrogen exist for every one of sodium.

While all the data provided by the Pioneer missions was being deciphered and analyzed, one fact was consistently brought home: Io is an incredibly deadly place. Shrouded as it is in the lethal Jovian radiation belts, its surface is subjected to constant bombardment by electrons and protons. Even the carefully fashioned and "radiation hardened" Pioneer spacecraft could barely survive a few hours in its vicinity; anyone who dared to venture there would be dead within seconds. Although astronauts of the future might visit Callisto (the farthest from Jupiter of the Galilean satellites), Io will probably remain an alien world.

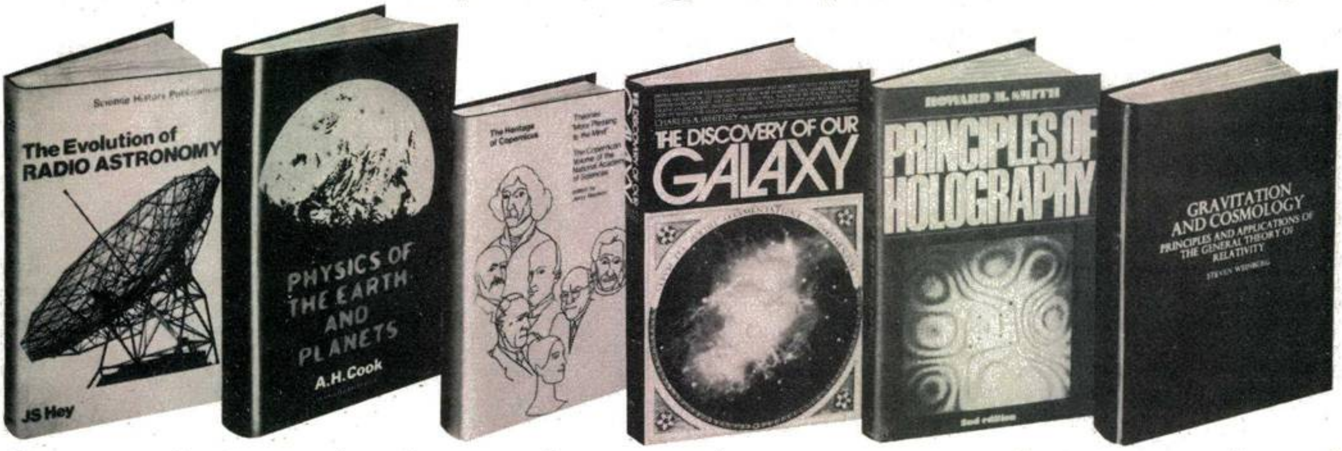
The glimpses that Pioneers 10 and 11 provided of Io and its environment were only enough to whet our appetites for further exploration. In 1977, NASA will launch two more probes toward the giant planets. These Mariner spacecraft will obtain more detailed television images of Jupiter and Saturn than we now have, and they will carry more sophisticated instruments to aid our study of the planets, their satellites and space environments.

One of these missions is tentatively scheduled for a close flyby of Io. If successful, it should photograph about half the satellite's surface with resolution of about 1/2 mile; during closest passage, the best pictures of a few areas will show individual features as small as 100 yards across. This coverage will be very similar to that obtained by Mariner 10 of the planet Mercury. It's difficult to grasp the meaning of such a tremendous jump in the amount of available information. It will be like going in one step from naked eye studies of the moon to today's largest and finest telescopes — bypassing 350 years of slow development from the time of Galileo to the present. If future discoveries about Io are as bizarre and exciting as those made in the past few years, Io may be a household word by the end of this decade.

As we learn more about the solar system beyond the asteroid belt, we are struck by the incredible variety we find. In addition to the awesome gas giant planets, there are satellites composed of water, ice or rock; the unique beauty of the rings of Saturn; its equally unique satellite Titan, with its massive atmosphere and a surface of great interest to exobiologists. But no world is stranger than Io, with a surface unlike any other in the solar system, wrapped in the embrace of Jupiter and exchanging lightning bolts with him.

Dr. David Morrison is an astronomer at the Institute for Astronomy of the University of Hawaii. Currently on leave at the University of Arizona and Kitt Peak National Observatory, his primary interests are infrared observations of planets, satellites and asteroids. He is also involved in exploration of the solar system by spacecraft. His book, **Minor Planets and Satellites,** *will be published in mid-1976.*

From Copernicus to Radio Astronomy... from the discovery of our galaxy to the Milky Way...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EXPLODING STARS

by
Bill Johnson

Picture a small star that has seen better days: It has used up most of its fuel and is well on its way to dull, uninteresting white dwarfdom. It's nothing unusual as most stars reach this point eventually; this particular star seems to be sinking toward quiet, peaceful oblivion.

But abruptly this tranquil scene is completely disrupted. In a sudden gigantic outburst of heat and energy, the star blasts away its outer shells, which fly off at top speed in all directions. Its brightness begins climbing and shoots up so rapidly that soon the star is blazing away with an intensity that nothing in its previous history can match.

On Earth, a new star seems to burst into view, altering a constellation's shape and rivaling the brighter stars. Observatory schedules are quickly rewritten, spectral analyses are begun immediately, and the star receives the designation of *nova.*

Such a dramatic series of events as this took place just last summer, when the brightest nova in 33 years appeared in Cygnus. And it excited more than the usual amount of interest that an exploding star arouses, for a nova that brightens as much as Nova Cygni 1975 did occurs only a few times in a century.

What caused this star's unusual behavior? What could have happened to the star that made it increase its brightness more than 40 million times in a single night? Might the same thing someday happen to our sun? In short, what exactly is a nova and why does it explode?

Novae belong to a class of stars known as *eruptive variables*. A variable is any star whose brightness changes over a period of time. Most have regular, predictable periods and are fairly sedate. But eruptive variables are different; they undergo unexpected and rapid upsurges in luminosity.

Unfortunately, we can't assign any star to this class until it actually does erupt. Before that, there is nothing to distinguish it from other stars. In fact, a good many prenovae are so dim they cannot even be seen from Earth. It might be said that the most interesting thing about a star that goes nova is — that it goes nova.

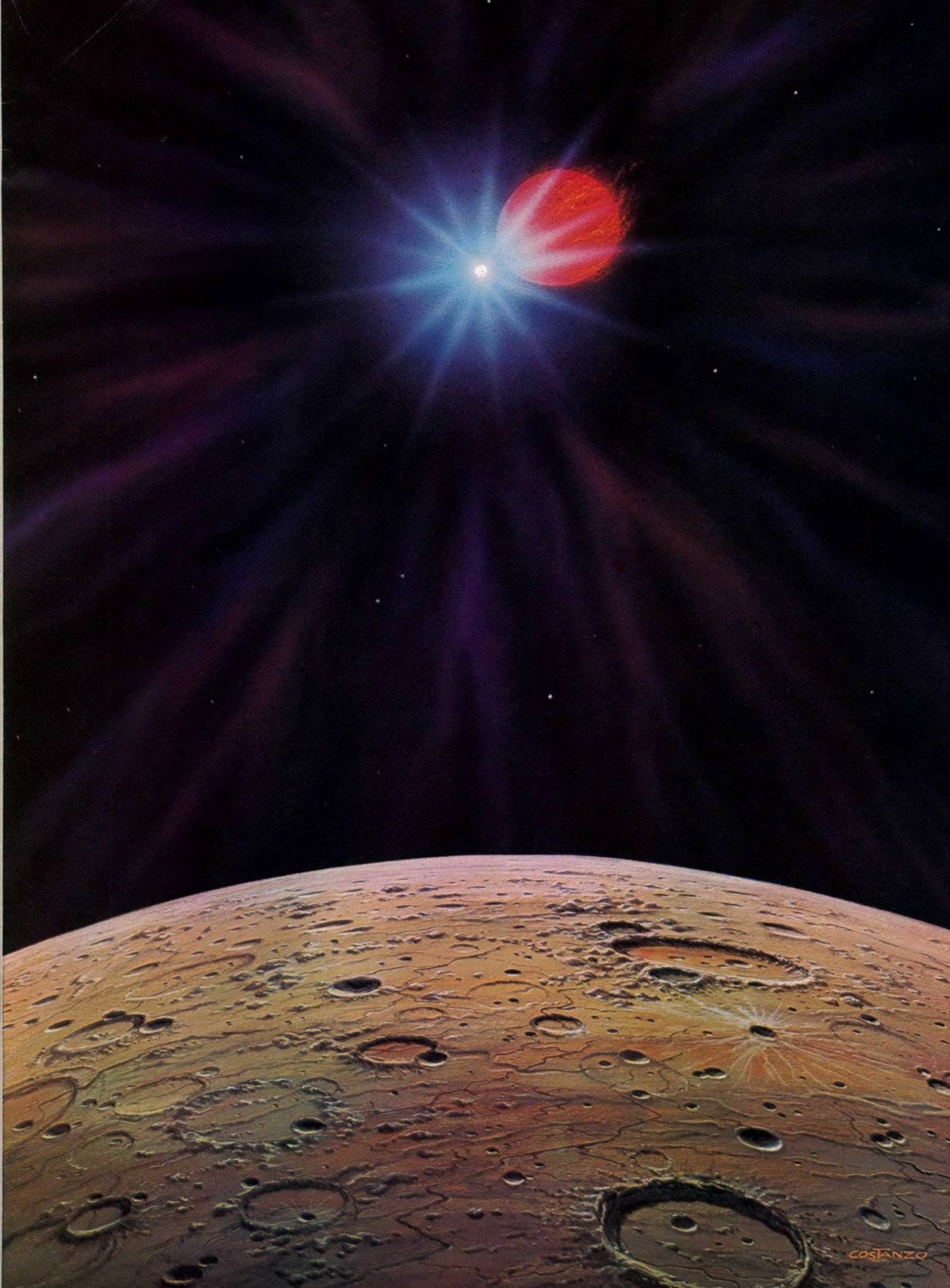
Because there is nothing unusual about prenova stars, there is no way of telling what is going to happen to them in the future. As a result, scientists have been unable to obtain their spectra, and we cannot know for certain exactly what kinds of stars they are.

A star's spectrum is the scientist's most useful tool for determining its characteristics — mass, luminosity, composition and density, among other things. But in only one case do we know the spectrum of a star in its prenova stage: that of Nova Aquilae 1918, the brightest in this century. When the star brightened, astronomers eagerly dug out its spectrum and checked it for unusual traits. But there were none in particular; the spectrum was that of a very hot, but otherwise nondescript, dwarf star.

(We could, of course, attempt to obtain a spectrum from every single star we can reach in the hope that it might eventually go nova; but such a massive, time wasting enterprise is better left uncontemplated.)

About all we can do is try and get the nova's spectrum during the first stage of its eruption — which means as quickly as possible after it is first noticed. Spectra taken at this time almost always indicate that the prenova probably belongs to spectral class B or A — that is, it has a high surface

A white dwarf, made unstable by matter from its companion star and its own intense gravity, is rapidly reaching the point of no return. Great hydrogen clouds are being expelled from its surface, and it will soon solve its problem in the only way possible — with an explosion. The hypothetical planet in orbit around the system probably will be destroyed in the blast. But this eruption will not end its life; the star will temporarily stabilize and then begin the process over again. Artwork by Victor Costanzo.


COSTANZO

temperature. Since most of these prenovae are so dim, the picture we obtain is that of a small, hot, blue or white dwarf.

This is a state which most normal stars reach near the ends of their long lives. After all, these prenovae don't appear from just anywhere; just like every other star, they have a particular place in the stellar evolutionary process. All stars can be assigned to a certain point on the *Hertzsprung-Russell diagram* — a graph which indicates, by a star's luminosity, surface temperature and other factors, its place in evolution. A typical star like our sun can be found on the main sequence along with the great majority of stars.

Now, when a normal star has used up a certain percentage of its hydrogen, it will expand into a red giant. Subsequent processes eventually contract the star again; if it's massive enough, it will become a dwarf. The generic name for stars that reach this phase is *white dwarf*. The actual color depends on surface temperature, but most of them belong to spectral classes B or A — precisely those in which the prenovae are found. (For a more detailed account of stellar evolution, see "From Dust to Dust", ASTRONOMY, June 1975.)

Does this mean that every star will become a nova as its life draws to a close? At first glance, it would seem so; but according to current theory, a particular set of circumstances must be met before a star can initiate the process that will lead to its explosion. If these conditions are not fulfilled, there can be no nova — or so astronomers think.

The first of these conditions is that the star must be a member of a binary system. A star cannot explode all by itself; it needs help from a neighbor, and the companion star of a binary provides all the assistance necessary. But not every binary will produce a nova; the two stars must be close enough together to have an effect on each other's evolution. Such a system has a period of mutual revolution measured in days or even hours. Finally, one star must, in its original stages, be more massive than the other. (If this theory is correct, incidentally, it means that our sun will not become a nova but will follow along the path marked out for normal stars — thus permitting us all to breathe a little easier.)

Let's follow an example of a close binary system through its lifetime and find out what theorists believe is the course of events that brings a nova into being. Keep in mind that the process covers most of the stars' lifetimes and is by no means as speedy as its description might indicate.

The first step is the actual formation of the binary from interstellar dust. By the time the stars begin to shine, one is larger and more massive than the other. To simplify matters, let's call the larger star A and the smaller one B.

For billions of years, both A and B are stable — everyday members of the main sequence. They revolve around one another rapidly, and perhaps tenuous streams of material flow between them. But basically they spin merrily along as a perfectly compatible pair (diagram 1).

However, being more massive than its companion, star A uses up its hydrogen fuel more quickly than B. When A reaches the point of critical fuel depletion, it begins expanding to the red giant phase of its evolution (diagram 2).

As star A grows larger, its expanding matter begins to reach toward the cooler star B. When A's gaseous outer layers finally pass the *Lagrangian point* (the place at which, in a system containing two bodies, the gravitational attractions of both bodies balance each other), star B immediately begins to absorb its material (diagram 3).

With added fuel, the companion B burns more fiercely and its own evolution is speeded up. It grows in mass and luminosity, and becomes a giant star itself. Its increased radiation pressure forces away the stream of gas falling onto its surface from A, blowing much of A's atmosphere into space.

As it loses gas, star A contracts. Hydrogen fusion continues in the outer layers of the star, but the core is changed into inactive helium "ash" (the byproduct of such fusion). Gradually A's hydrogen supply is exhausted, and the gravity at the core pulls the outer layers down toward its center (diagram 4).

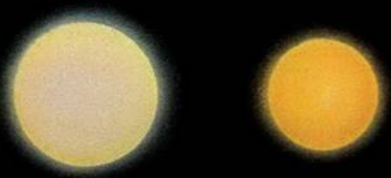
Eventually star A shrinks to a white dwarf; its mass is incredibly compressed into a tiny space. The outer layers' collapse onto the core adds pressure and heat, and the helium at the center begins its own fusion. Radiation pressure from the core prevents any further collapse, and the dwarf reaches a state of relative equilibrium (diagram 5).

If the white dwarf were alone in space, it could now become stable and continue along its tedious path to extinction. But because it does belong to a binary system, it cannot achieve the necessary stability. The next stage of nova formation now begins.

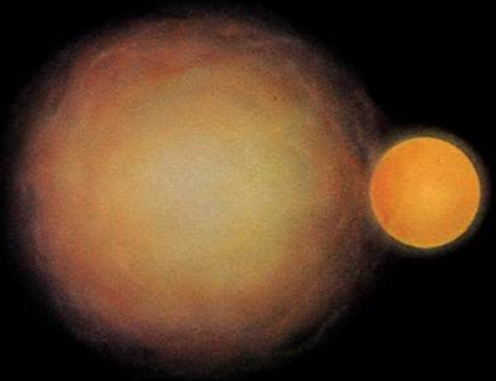
The white dwarf's intense gravity begins to affect its larger, cooler partner. Hydrogen is pulled from the outer layers of the now distended star B onto the surface of the dwarf, and slowly a huge cloud of hydrogen forms around A (diagram 6).

The surface temperature of the white dwarf is too low to fuse hydrogen, so more and more of the gas drawn from B falls on the dwarf and drifts unfused on the surface. The hydrogen's mounting pressure raises the temperature at star A's core over 100 million degrees, but the degenerate matter of the core prevents this heat from reaching the surface and beginning hydrogen fusion.

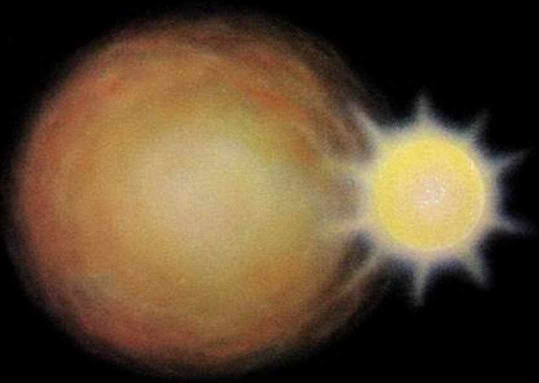
Gradually the pressure of the hydrogen gas envelope contracts the core further and more heat seeps through to the outer layers of the star. The surface temperature rises until the lower levels of the hydrogen cloud finally ignite.



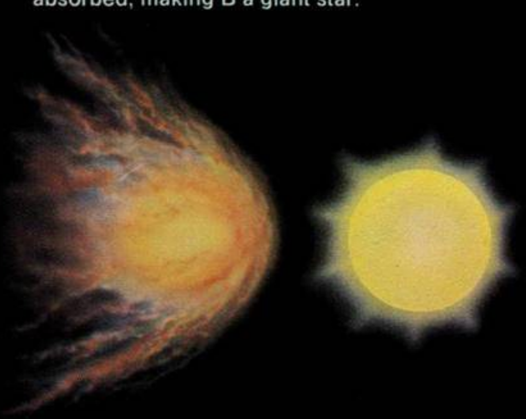
1. Stable binary.



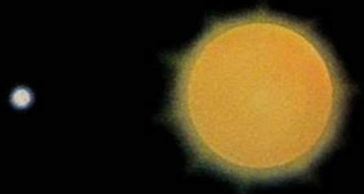
2. Star A becomes a red giant.



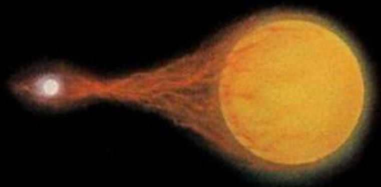
3. Star A's atmosphere reaches B where it is absorbed, making B a giant star.



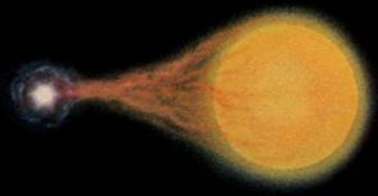
4. Having gained mass from A, star B's increased radiation pressure forces A's atmosphere into space.



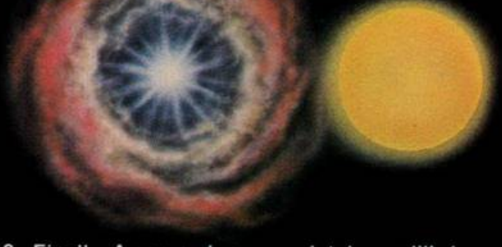
5. Star A becomes a white dwarf and the binary stabilizes.



6. A's intensified gravity pulls away star B's outer layers, forming a hydrogen cloud around itself.

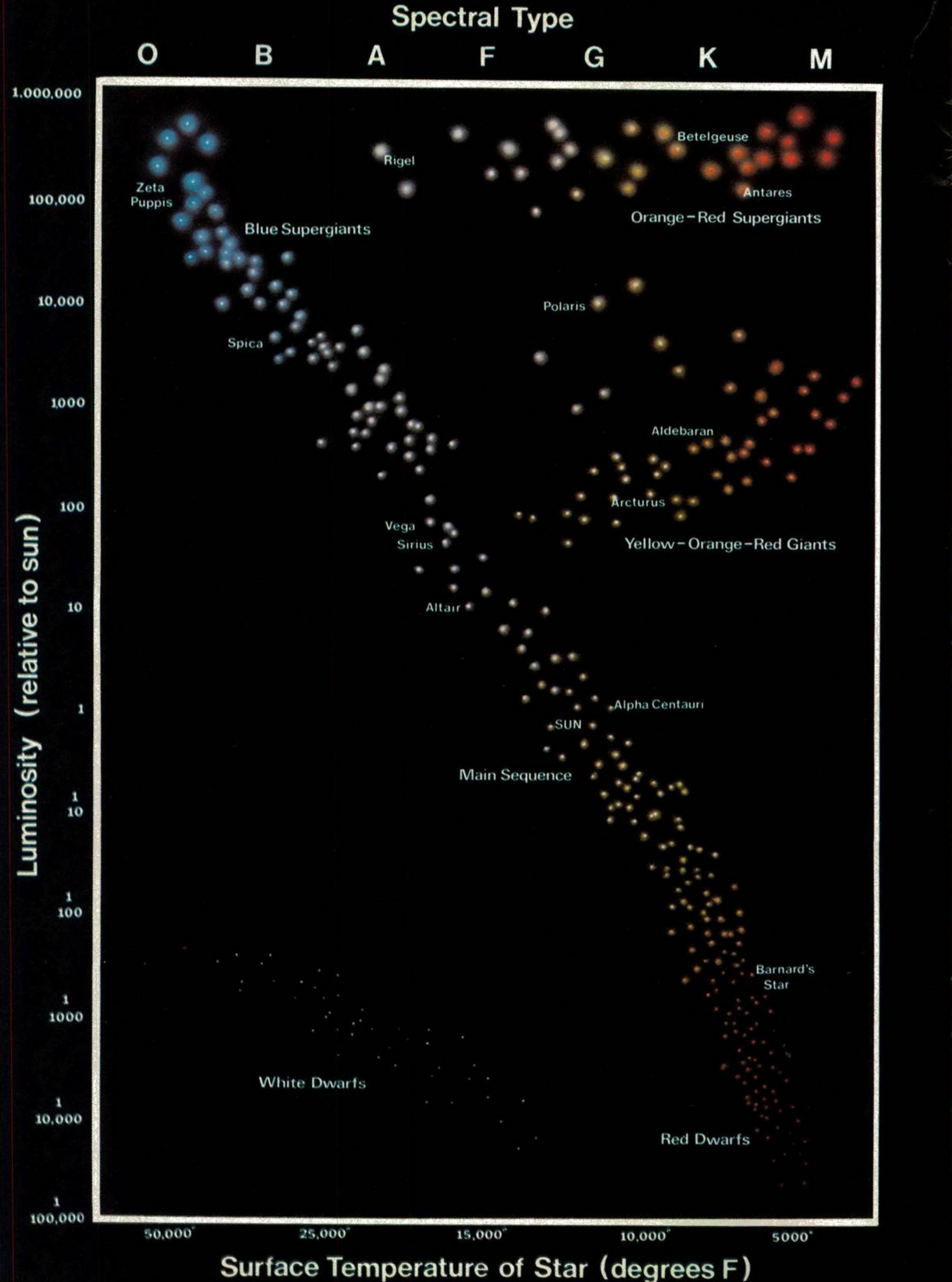


7. Repeatedly, A's core contracts and heats from the weight of the hydrogen cloud; surface temperature rises, forcing the upper layers of the cloud away.



8. Finally, A can no longer maintain equilibrium and expels the hydrogen cloud in a shell beyond its gravitational reach.

Artwork by Victor Costanzo.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K
M
Luminosity (relative to sun)
1,000,000
100,000
10,000
1000
100
10
1
$\frac{1}{10}$
$\frac{1}{100}$
$\frac{1}{1000}$
$\frac{1}{10,000}$
$\frac{1}{100,000}$
Zeta Puppis
Blue Supergiants
Rigel
Betelgeuse
Antares
Orange-Red Supergiants
Polaris
Spica
Aldebaran
Arcturus
Yellow-Orange-Red Giants
Vega
Sirius
Altair
Alpha Centauri
SUN
Main Sequence
Barnard's Star
White Dwarfs
Red Dwarfs
50,000°
25,000°
15,000°
10,000°
5000°
Surface Temperature of Star (degrees F)

As soon as this surface hydrogen begins to fuse, radiation pressure forces the upper levels of the cloud away, thereby decreasing its pressure on the star. The flare-up in core temperature subsides. Surface heat again drops below the fusion ignition temperature — but it remains higher than its previous level (diagram 7).

This process is repeated over and over. Hydrogen clouds again begin to subside onto the dwarf, and the core temperature rises once more. The bottom layers of the cloud ignite and blow away the outer shells. Each time the reaction dies, the temperature of star A's surface is higher than before.

The energy level inside the white dwarf rises slowly as the pressure of the hydrogen cloud increases. Fusion takes place farther and farther into the cloud, but its depth and pressure increase faster than the temperature rises.

At this point, star A's core begins to superheat — and then everything happens at once. At the same time that a collapsing envelope of hydrogen gas presses down, the surface temperature increases. Hydrogen caught between these two forces reaches fusion temperature and explodes. The middle of the cloud ignites the outer cloud, fusing it too. Meanwhile, the dwarf is compressed by the explosion, and a shock wave overheats the core which pulses outward. An explosive blast wave erupts from the white dwarf, expelling the hydrogen cloud in a shell beyond the gravitational capture of the dwarf.

The expulsion of the outer shell is the equivalent of a rapid increase in the radiating surface of star A. As all the hydrogen fuses at once, the dwarf's brightness immediately skyrockets, thus producing the "new star" seen from Earth (diagram 8).

After the eruption, the core temperature of star A drops rapidly due to the loss of the hydrogen cloud's pressure, and the nova's brightness begins its downward slide. However, the gaseous shell blasted away in the explosion continues to race outward. Made visible by its own fusion and light from the star, the shell will continue growing and take on the appearance of a nebula surrounding the star. Eventually it will dissipate into space.

Star B should not be seriously affected by the explosion. Hydrogen will eventually start to spiral down to the dwarf again, building toward another explosion in the future.

Novae do explode more than once. Unlike supernovae which destroy themselves in a single cataclysm, there is no theoretical end to a nova system once the chain is started. Most of the material expelled by the blast is from the hydrogen cloud around the dwarf, and the star itself actually loses less than one percent of its own matter. It lives on to begin the cycle once more, and will nova again and again.

One group of eruptive variables are the *recurrent novae*. These are stars that became reasonably bright novae, sank into dimness — and then exploded again several decades later.

Even faster are the *U Geminorum stars*. These exhibit large, sudden increases in magnitude, and then drop just as quickly to their original brightness. The process takes only days. Although these outbursts are unpredictable, being irregular, they may come as often as every 60 days.

What we are witnessing here may be nova systems at various ages. When a nova gets as bright as Nova Cygni 1975, the chances are it is experiencing its first outburst. Such a star is called a *virgin nova*. With a higher surface temperature after its explosion, the surrounding hydrogen gas cloud that collects will ignite much faster the second time, before a huge volume of it can be collected. The result will be another nova, but one not as brilliant as the first. The time elapsed between a nova's first two outbursts may be on the order of 20,000 years.

But as it takes less and less time to build up to each explosion, the cycle speeds up. Eventually, the point reached is that of the U Geminorum stars — a fresh outburst about every couple of months. By now, the dwarf is gobbling up its companion's hydrogen supply so quickly that the constant machine gun fire of novae will probably drive the companion away — thus finally ending the cycle and leaving behind just another white dwarf.

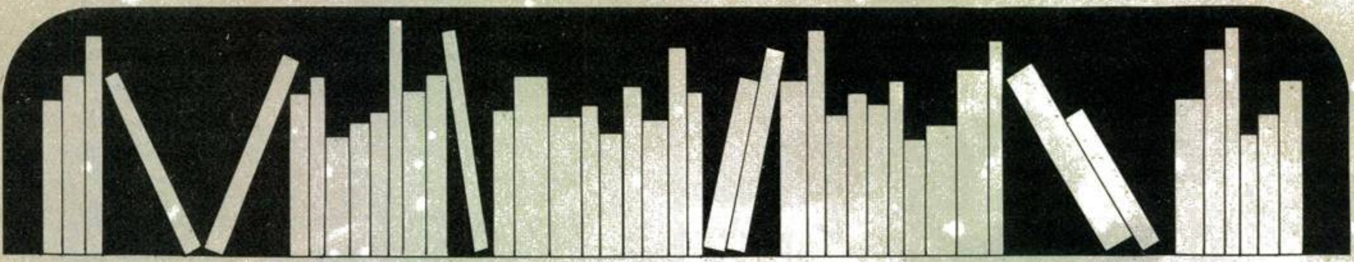
Such is the picture we have of nova formation. And the greatest challenge to it may be coming from Nova Cygni 1975 itself.

Nova Cygni's decline in brightness was very rapid — much more so than that of a common nova. Its spectrum has shown complications that other novae don't exhibit. But some astronomers have calculated that these factors can be accounted for if the nova's companion is ignored, or if it doesn't exist. Nova Cygni may be something new: a star that *did* explode on its own, perhaps by accreting matter from interstellar space. If so, our current theory of nova formation may be invalidated — or shown to be simply one of several possibilities.

We should finally note that a common nova contributes nothing to either the universe or to our knowledge of it. They are freak accidents, and in the last analysis, they must probably be found guilty of sensationalism.

Every star can be assigned its proper place on the Hertzsprung-Russell diagram, indicating its state of evolution. The normal processes of stellar growth will take a star from the main sequence, where it spends most of its life, through the giant phase and down to the white dwarf region. It is here that prenova stars are found — but not every dwarf will become a nova. A great deal depends on the circumstances surrounding the dwarf's formation. Artwork by Victor Costanzo.

Bill Johnson is an undergraduate student at the University of Iowa in Iowa City, where he is currently specializing in journalism and physics.



ASTRONOMY REVIEWS

NASA FACTS SERIES

The Spectrum
wall chart, $.60*

Viking Mission to Mars
16 pages, paperback $.50**

Why Survey From Space?
10 pages, paperback, $.45***

NASA Facts is an educational publication of NASA's Office of Public Affairs, Educational Programs Division, and is distributed free to teachers who write in with their school address. The timely and colorful booklets and wall posters are excellent teaching resources for grade school and high school classes.

Every astronomer should have his own copy of the "Spectrum" poster just released by NASA. Alongside a scale of electromagnetic frequency, this chart is illustrated with typical wavelength emitters and common instruments for observations at these wavelengths. Several columns of text describe the various targets of astronomical observations at different frequencies, the different classes of frequencies, and even give a few words on gravity and sound waves.

"Viking Mission to Mars" is a short but colorful pamphlet about the most expensive space probes ever shot into space (each Viking cost more than a manned Apollo moon shot). A good description of the spacecraft and its mission is given, along with a unique color photograph of some terrestrial landscape, taken with the same kind of camera which is on both Viking landers. Indeed, the color photographs in this short booklet are better than those in many hardcover books with hundreds of pages.

Although astronomers in space may always want to keep their eyes on the sky, another target will be in view below them: the planet Earth. "Why go up there to look down here?" asks the third **NASA Facts** publication, and then proceeds to explain with amusing cartoons why the best view of Earth is from space.

All three pamphlets are inexpensive, but can be very valuable. NASA deserves congratulations on its new programs in education and public relations. *James E. Oberg.*

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* * *

Space Station: Key to the Future

40 pages, paperback, $.45*
U.S. Government Printing Office

The only funded manned space program on NASA's books is the reusable Space Shuttle rocket plane, due to begin operations in 1980. This little pamphlet describes the logical next step: a manned space station permanently in orbit above Earth.

Study contracts with aerospace contractors have only recently been assigned, so this book cannot describe the actual space station which will be built sometime after 1985. However, it does describe the functions, structure and potentials of space stations in general.

Three dozen illustrations show many aspects of life on space stations and the assembly of the large space homes from smaller modules brought up from Earth inside the Space Shuttle. The sketches are well done and appropriate.

Why build a space station at all? Don't expect new revelations or inspirations here; the old answers are well summarized, and they are still valid. We want to live in space for long periods of time because it will be good for meteorology, Earth resources, materials processing, and sciences such as astronomy, biology and physics. Judging from the results of past exploration on Earth, we may ultimately find that the most valuable results of this new frontier will lie in applications we've yet to imagine.

There are no specifics about actual hardware, and even the Space Shuttle is incorrectly described. Skylab is barely mentioned. This is a pamphlet aimed at the future — at young readers who will someday serve as crewmen of these giant islands in the sky. For them, the book is an invitation to look into their own future, and see themselves in the drawings of space station crewmen. *James E. Oberg.*

**Stock number NASA-EP-75; for sale by Superintendent of Documents, Washington, D.C. 20402.*

* * *

Pictorial Guide to Planet Earth

by FREDERICK I. ORDWAY III

191 pages (illus.), hardcover, $12.95
Thomas Y. Crowell Co. (1975)

After brilliant reconnaissance of the solar system from Mercury out to Jupiter and beyond, the United States space program is concentrating more of its attention — and public relations — on Earth studies that can be justified on the basis of short-term economic return. **Pictorial Guide to Planet Earth**, though not a government publication, is a perfect example of this shift of emphasis. Although informative and well-reasoned, it reduces the grand adventure of the exploration of space to humdrum dollars-and-cents arguments that may convince a businessperson but will never inspire a boy or girl to dream of the wonders of space.

Ordway is a well-known science writer, and in this volume he pursues his craft carefully and conscientiously. But for all its technical accuracy and wealth of facts and figures, this book shows no evidence of a questioning and critical mind.

In chapters covering space application in mapping, geological studies, monitoring of rivers and snow and ice cover, surveys of agriculture and forestry, and studies in oceanography and meteorology, Ordway quotes experimentors on NASA Earth resources and meteorological satellites at length. As might be expected, these engineers and scientists consistently justify their work and point to its present and potential economic benefit. Undoubtedly their arguments are predominantly accurate; taken together they provide ample justification for study of Earth from space. Ordway frequently points out the fragility of the terrestrial ecosystem and the rapid rate at which our natural resources are being depleted. He argues convincingly that intelligent use of data from the space program is an integral part of a more rational and less destructive partnership between homo sapiens and planet Earth. However, the constant quotation of essentially the same self-serving arguments, presented in the standard unimaginative, bureaucratic language of technical reports to NASA, dulls the reader's wits and leaves him convinced but suffering from a headache.

This is a pictorial guide, and it is the pictures — more than 100 with about half in full-page format — that provide the main rationale for this book. Unfortunately, the reproduction quality is generally so poor that the pictures lose most of their beauty and impact. The text and captions frequently describe features that are all but invisible on the illustrations. Only in 16 color pages grouped together at the center of the book are the magnificence and clarity of the space views of Earth revealed.

A reader seeking a book that pleases the senses and inspires the imagination would do better to bypass the present volume and instead purchase the excellently produced NASA books of Gemini photographs of Earth — and to urge the government to publish similar volumes of ERTS and Skylab photography. *David Morrison.*

* * *

The Second Fifteen Years in Space
edited by SAUL FERDMAN

201 pages, hardcover, $15.00*

Chroniclers usually measure time in units of decades, jubilees, centuries or millennia, but this book is based upon an American Astronautical Society conference which needed a catchy theme. Since space exploration began in earnest little more than 15 years ago, the conferees decided to examine the *next* 15 years.

Almost all the specialists agreed that they would be different from the first 1-1/2 decades. The theme of the future will be "exploitation" rather than "exploration", and one of the keynote speeches was given by an industrialist who remarked that space "becomes an exploitable resource, not just a medium."

Science, too, will benefit according to a spokesman for the National Science Foundation: "I can safely say that there can be only one response for the scientific mind in contemplation of the next 15 years in space from the scientific viewpoint — a sense of awe." But the words are not backed up by real examples; the book turns to the engineering rather than the scientific frontiers.

In this role, the book is a valuable and informative teacher. Here we learn about the miraculous SSME (Space Shuttle Main Engine) which makes the whole Space Shuttle rocket plane feasible. This new rocket booster is three times as pressurized as the Saturn 5's "F-1" engines, with ten times the exhaust temperature, five times the turbopump power, ten times the lifetime, half again the magic number of "specific impulse", but only 1/3 the thrust. New aerospike engines now on the drawing boards will be even more powerful.

Computers in spacecraft and new communications technologies are also covered in easy to understand but very detailed presentations. And if you think you've heard all there is to hear about the Viking missions to Mars, you are mistaken. A special report by the project director discusses the engineering constraints of a successful landing in the same detailed, yet lucid, style.

Astronaut Donald Slayton, chief of the astronauts and veteran of the Apollo/Soyuz flight, closes the book with another visionary chapter entitled "Astronaut of 1988". What kinds of people will be flying in space that year? What kinds of background must they have? What kinds of duties will they perform? Slayton gives his views on this topic which must certainly be of interest to thousands of would-be astronauts now in their teens.

As with any conference proceedings, this book is unconnected and of varying quality. But the individual papers are all of interest and are all useful in anticipating the engineering advances of the next few years in space. *James E. Oberg.*

**Distributed by Univelt, Inc., P.O. Box 746, Tarzana, CA 91356.*

* * *

Eyes on the Universe
by ISAAC ASIMOV

274 pages (illus.), hardcover, $8.95
Houghton Mifflin (1975)

According to this latest Asimov book, the history of astronomy is really the history of telescopes. As soon as each new bigger instrument was built, observers saw new celestial objects and learned more about the universe. The driving factor was not the astronomer's intelligence but the instrument-maker's craft.

Subtitled "A History of the Telescope", this book follows the development of that industry: lens grinding, mirror manufacture, theory of optics, radio telescopes, and ultimately space-borne observatories. The astronomers and their actual discoveries seem secondary to the problems of extending their vision.

Decade by decade, Asimov traces the engineering problems and implications of refracting versus reflecting telescopes, as either type of instrument prevailed for a few generations until the other type advanced through new technological breakthroughs. (This theme should be of great interest to anyone who owns his own telescope and wonders about its ancestry.) Problems of chromatic aberration, light gathering and resolution, lens formation, edge focusing, etc., all succumbed one by one — and Asimov tells how. People who build their own telescopes will enjoy these sections about the techniques which led up to the present methods.

Showing how these problems were overcome is a little harder, but this is not the author's fault. The book's photo section was unfortunately put together by someone else, independently of the text; the two sections are not well-coordinated. A reader would be advised to review the photographs and sketches before beginning the book, so he will know when the text has been supplemented by illustrations.

Asimov describes how a 17th century astronomer "discovered" that one of the Big Dipper handle stars was really a double star "that could be seen separately by telescope but not by the unaided eye". But American Indians were using that particular double star as an "eye test" for their youngsters for centuries. A nitpicking reviewer might also point out that the automatic drive of a telescope does not "keep the stars in focus" — careless wording.

All in all, the book is excellent — another "typical Asimov" survey of an interesting aspect of astronomy. (Is "The History of the Microscope" next?) Along the way, the author painlessly exposes the unsuspecting reader to important lessons in history, observation techniques, optics, mechanics, human nature, radio theory, and even from time to time astronomy. No, the exposure is more than painless — Asimov makes it a pleasure. *James E. Oberg.*

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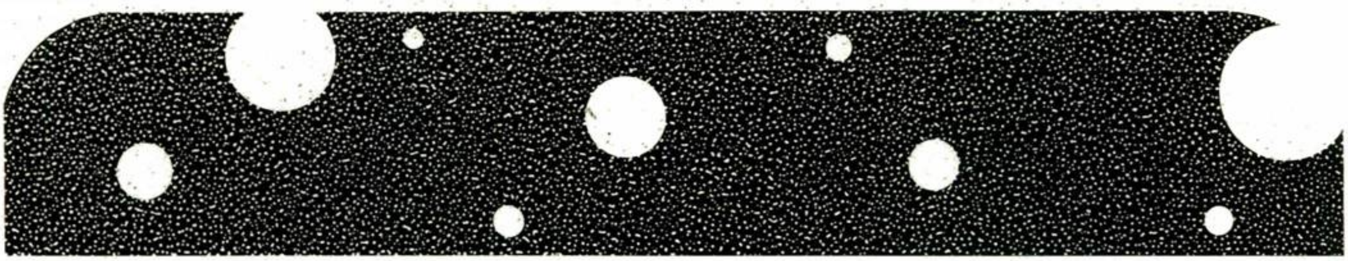


STELLAR FRONTIERS

How Far Is Up?

by

Gerrit L. Verschuur

We take it for granted that the stars and galaxies we see at night are far away, but how do we know? Not only that, just how distant are they? The problems involved in finding the distances to celestial objects are some of the most fundamental and complex — and also some of the most fascinating — in astronomy.

This particular jigsaw puzzle contains many pieces. The first important piece involves finding the distance to relatively nearby objects: the sun and planets. Modern astronomy does this by forming a model of the solar system and of the planets' motions about the sun.

Planets orbit the sun according to Kepler's *laws of planetary motion.* For our present purposes, the most important of these laws is the third. Expressed simply, this law states that the square of a planet's *sidereal period* (the length of time it takes for one circuit of the sun) is in direct proportion to the cube of its average distance from the sun. In other words, if we know how long a planet's year is — and it is found simply by measuring the time from one superior conjunction to the next — we can easily calculate its distance from the sun in *astronomical units* (the average Earth-sun distance). Once we find these measurements, we know the relative scale of the solar system.

Today, astronomers can find the distance of Venus from Earth much more precisely by bouncing a radio signal off that planet and measuring the time needed for its echo to return. This method is called *planetary radar*; such experiments are carried out in the field of radio astronomy. Since we know radar waves move through space at the speed of light, we can calculate the distance the signal traveled by measuring the time it took for the round trip. Using these observations, we can find the exact length of the astronomical unit using simple geometry. This yardstick used by astronomers is about 93,000,000 miles (actually 92,960,131 miles, give or take a few).

The result is more exact knowledge of the solar system's scale. Given these measurements, combined with orbital calculations, we can find the exact positions in space of all the members of the solar system, and can forecast these positions for many years into the future. The practical application of this information allows us to send spacecraft to the planets.

To find distances to the nearer stars, astronomers make use of a phenomenon called *parallax.* Its effects can be simply demonstrated. Imagine you are looking at a telephone pole 100 yards away, located about 20 yards in front of a house. If you take a step or two to the side, the pole will appear to move against the background of the house and will seem to be standing before a different part of it. Next, look at a telephone pole in front of a much more distant house; this time, when you step to the side, the pole will appear to move a shorter distance before it. If you perform the experiment on a similar arrangement located at such a distance that you need binoculars to see the pole, it will not appear to move across the front of the house at all.

The Large Magellanic Cloud (right) contains many of the variables known as Cepheids. Discovery of the Cepheids' period/luminosity law enabled scientists to find their absolute magnitude and distance. Measurement of the distance of the Cepheids in the Magellanic Clouds proved their extragalactic nature. Photograph by Hans Vehrenberg.

The same effect can be observed with the stars. Because Earth is orbiting about the sun, it has an equivalent motion — on a far larger scale, of course — of a step to the side, and back again, every year. Consequently, the nearer stars appear to move back and forth against the background of the more distant stars during the year. (Actually, these stars will trace out ellipses, matching Earth's orbit.) The effect is called parallax, or more properly, *parallactic displacement.* This apparent shifting of position is very small, but it can be measured; using geometry, the astronomer can calculate the distance to the stars that exhibit parallax. Distances to about 100 light-years can be measured in this way.

However, 100 light-years is a very short distance by astronomical standards. To find distances of stars located farther away, we can use any one of several possible approaches. The most important of these is the observation of the bright variable stars known as Cepheids (named after Delta Cephei, the prototype of their class). Cepheids are short-period variables; some of them change in brightness from day to day. Knowledge of their unique properties can be used to determine distances to the groups of star clusters, or even galaxies, in which they are located. We can do this even without understanding why the Cepheid variable star varies at all!

The story of the Cepheids began about 60 years ago. Astronomer Henrietta Leavitt, studying the Cepheids in the Magellanic Clouds, made an important discovery: There seemed to be a direct relationship between the stars' periods of pulsation and their average apparent brightness (the brighter appearing ones had longer periods). This relation had never been noticed before; it appeared to offer a clue to finding the distances of the Magellanic Clouds (MC).

We can consider the Cepheid variables in the MC — the two small, irregular galaxies situated outside the Milky Way galaxy — as all located about the same distance from us. Because the MC are very far away, one variable might lie on the near side of one of them, and another might be at the farther end. But our average distance to the clouds is so large that such an effect does not make much difference. To use an example closer to home: If you live in central Los Angeles, you can say that everyone in New York lives the same distance away from you than another person on the far side of that city. Since New York and Los Angeles are 3,000 miles apart, another mile here or there will not account for much — for all of new York is at one average distance from Los Angeles.

Therefore, if the distance to one Cepheid in the Magellanic Clouds could be found, astronomers would know the distance of the clouds themselves.

Henrietta Leavitt had observed the *apparent* magnitude of the Cepheids. If she could discover the average distance of the clouds, she would know the *absolute* magnitude of the Cepheids found there. But, of course, the distance to the Magellanic Clouds was unknown — although they did appear to be quite far away.

If we know the absolute brightness of a star — from analysis of its spectrum, for example — and then measure its apparent brightness, we can estimate the distance the light must have traveled for it to have lessened as much as it has. This is true for all stars. In this case, the luminosity of the Cepheids depended on their periods. Therefore it should have been possible to find the absolute brightness of any Cepheid once its period was measured. Unfortunately, this couldn't be done for the Magellanic Cloud Cepheids, since Leavitt's discovery had so far only correlated periods with their apparent magnitudes, and their distances were still unknown.

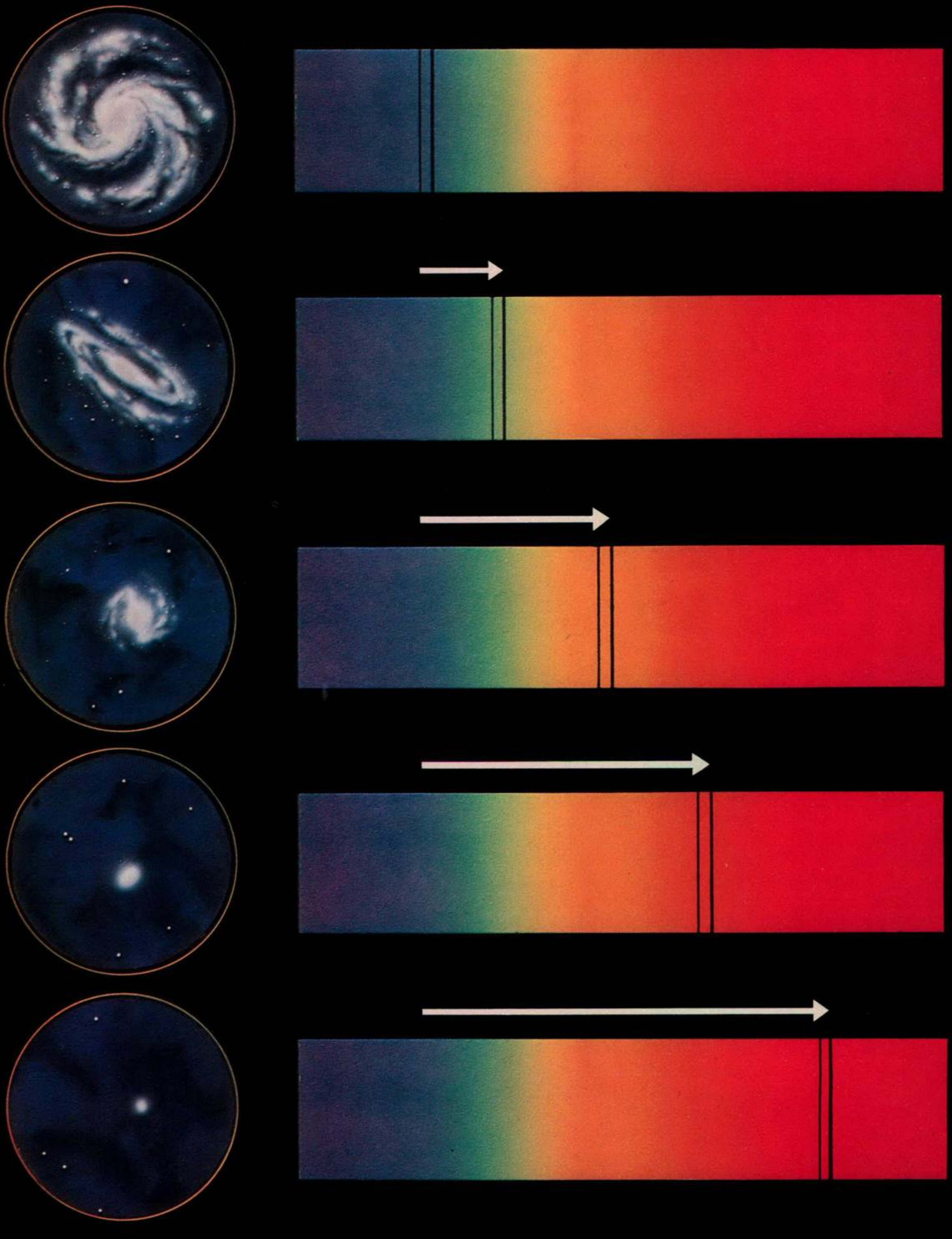
However, if the absolute brightness of a Cepheid variable anywhere *inside* the galaxy could be measured by some other method, then astronomers would know that a period of three days corresponded to a certain average absolute magnitude. This knowledge could then be applied to the Magellanic Cepheids. Astronomers could measure the apparent magnitude of a three-day Cepheid in the clouds, calculate its absolute magnitude from that information, and determine its distance. The true brightness of a Cepheid with a different period would be found automatically because of the period/luminosity relationship. This relation had never been noticed for Cepheids in our galaxy because their distances from Earth varied greatly and their apparent magnitudes differed from each other. It was only because the Magellanic Cepheids were all at relatively the same distance that the period/luminosity law could be observed.

One hoped-for result from study of the phenomena found by Leavitt was that scientists might at last be able to prove conclusively that the Magellanic Clouds were so far away that they could only be other galaxies. Before the 1920s, the existence of other galaxies in the universe was strongly suspected — but had never been proven.

To find the distance and absolute magnitude of at least one nearby Cepheid — and allow the standardization of the period/luminosity law — a method involving the *proper motion* of stars was used.

This experiment for determining distance was performed as far back as 1913. A large number of stars in a certain part of the sky are examined. We must assume that their average motion toward or away from us (*radial velocity*) is the same as their average motion in a direction at right angles to this

When a source of light is moving away from an observer, the dark lines in its spectrum — caused by certain elements' absorption of radiation at specific wavelengths — are shifted toward the red end. The spectra of all galaxies exhibit strong redshifts, demonstrating that the galaxies are headed away from us. The faster a galaxy is moving, the greater the redshift its spectrum shows. Artwork by Victor Costanzo.



line (their *transverse velocity*). [If the stars' motions are random, these are safe assumptions to make.]

We can measure the radial velocity of our group of stars by examining the shift of the absorption lines in their spectra. For example, this might tell us that in one year the average motion for these stars is 1/100 of a light-year toward us. Next, although we cannot directly find the stars' transverse velocity, we can measure the change in position of a star as seen against more distant background stars. Called proper motion, this is the actual change of a star's position that occurs because of the star's motion through space. (This should not be confused with parallax, which is an apparent motion of stars caused only by Earth's movement about the sun.)

We measure the proper motion and find that it is one second of arc per year. We then know that this one second of arc corresponds to the 1/100 of a light-year measured earlier for our particular group of stars. Now we can easily estimate the distance at which a line 1/100 of a light-year long would appear to cover an angle of one second of arc — and the average distance to our group of stars is known.

This method was applied to a Cepheid variable in our galaxy; and although the method is highly uncertain — depending as it does on several more or less forced assumptions — it did allow the Cepheid's absolute magnitude to be approximately found. Thus the period/luminosity law was standardized, and by applying it to the Magellanic Cloud Cepheids, their distance was found. Subsequently, the distance to any galaxy containing a Cepheid variable could also be estimated. It soon became apparent that the universe was indeed full of distant galaxies like the Milky Way — or "island universes" as they were called for a time. But it appeared that the Milky Way was the largest of them all, and this was too great a coincidence to go unchallenged.

About 25 years later, a second type of Cepheid variable was discovered. The first type was associated with young stars, while the second — known either as Type II Cepheids or W Virginis stars, after their prototype — was associated with older stars, and their period/luminosity laws were not the same. When this difference was allowed for and the distances sorted out, the universe changed its size. The other galaxies were not smaller than the Milky Way, but farther away than had been thought; our galaxy was no longer a giant among pygmies.

The entire episode took decades to be resolved, and today there are different methods of finding distances to stars and galaxies. However, the Cepheids did provide proof of the extragalactic nature of the Magellanic Clouds and the nearer galaxies, leading to the first conception of the universe's gigantic size.

Cepheids are the most useful tool for determining distances to galaxies in which they can be seen. But there are countless galaxies that are too far away for individual Cepheids to be made out. If we want the distances to such galaxies, we depend on entirely different methods which involve measuring their so-called *redshifts*.

When we observe the spectrum of any star, or of the combined light of all the stars in a distant galaxy, we notice distinct dark lines at specific wavelengths. Such lines are caused by the absorption of radiation at these wavelengths by atoms of certain elements located between the light being studied and the observer. Each element has its own signature in the continuous spectrum; it can be identified by the wavelength at which it absorbs radiation. In the case of a distant galaxy, there are several elements that always absorb its light; these include calcium and magnesium. If a light source is moving away from the observer, the absorption lines will shift their positions toward the red (longer wavelength) end of the spectrum. This is known as the *Doppler effect* or, more commonly, the redshift.

In 1926, galaxies were still referred to as nebulae, since their extragalactic nature was still unproven. (We can still find references to the "Andromeda nebula" in older texts.) But in that year, scientists discovered that the spectra of virtually all those nebulae suspected to be distant galaxies showed a pronounced redshift. The unavoidable conclusion was that they were all located outside the Milky Way and were moving away from it.

At first, it appeared that since everything was moving away from the Milky Way, our galaxy was located in the center of the universe (making another remarkable coincidence). But this was later shown to be an optical illusion, and the Milky Way was not special or different from other galaxies.

Edwin Hubble demonstrated in 1929 that the fainter galaxies appeared to be moving away from us faster than the brighter, and presumably nearer, ones. He established a definite relationship between the distance to a galaxy and its redshift, which states that a galaxy is receding from us at 80 miles per second for 3.2 million light-years of distance from us. Originally, the value of this *Hubble's constant* (as it came to be called) was thought to be 800 miles per second per 3.2 million light-years, but the most modern estimates place it nearer the former figure. Today, in order to estimate the distance to a newly discovered galaxy or quasar, astronomers measure the redshift, and if it is (for example) 3,200 miles per second, then they know that the distance must be about 128 million light-years. Studies of redshifts showed that the more distant a galaxy was from us, the faster it was moving away; this can be explained only if the universe is expanding in all directions.

Refinements in distance-measuring methods are continually being made; the chain of information that is required for such a final result as Hubble's constant is very complex. We have given only a simplified overview here; further discoveries will have to be made before the full story can be written.

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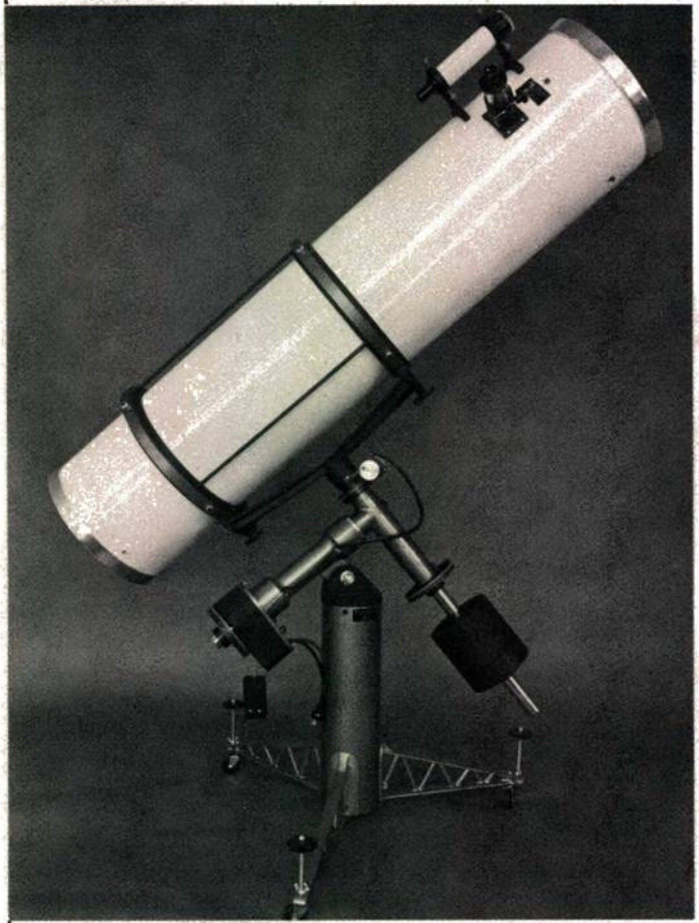

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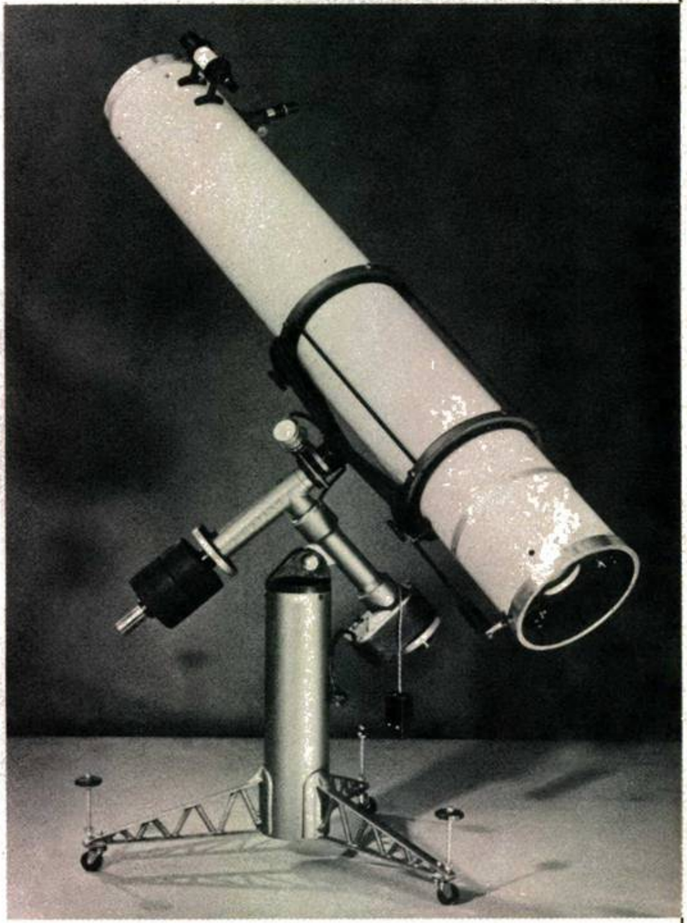

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PHOTOGRAPHY IN ASTRONOMY

Astrophotography: A Woman's View

by

Diane L. Payton

After studying the main articles in the October 1975 issue of ASTRONOMY, my attention was drawn to In Focus and the letter from Sharon Hoveln. The truth of her observation that there are more male than female astrophotographers came as quite a shock. It does indeed seem that men have a monopoly when it comes to amateur astrophotographers whose work is included in ASTRONOMY's pages!

Somehow this never registered, even though I always read the magazine very thoroughly — including captions and credit lines. After reading a few issues you almost feel you "know" many of the most frequent contributors, both by name and by their favorite subjects.

Could it be that Sharon and I are the only female ASTRONOMY readers who enjoy sky photography? Even though women represent only 7-1/2 percent of ASTRONOMY's readership, it seems unlikely that only two aim their cameras toward the sky.

But let's suppose only 1 in 10 of that 7-1/2 percent ever shoots the sky, that only 1 in 10 of that small number loves it enough to take the time and effort to improve, and that only 1 in 10 again has ever considered sharing their work with others through ASTRONOMY. Then, combined with other number-reducing factors, the percentage of women astrophotographers is "astronomically small" and it's conceivable that the resulting number could be only two. It would make the world less lonely, though, to know there might be others — somewhere — who share our interest.

Interestingly, there is a similarity here between astrophotography and general photography. More men than women belong to general interest photography clubs. Although these active women photographers are not quite as outnumbered as among ASTRONOMY's readership, we still hold a one in five minority in these groups.

Why? The only thought that comes to mind is that both astronomy (astrophotography to a greater extent) and serious amateur photography are more technically oriented pursuits than are most other avocations. But technical orientation alone certainly doesn't explain why either subject should be of less interest to women than men.

ASTRONOMY has been a very well received "visitor" at many photography club meetings where most people are not astronomy oriented. Sadly, some would have difficulty even locating the Big Dipper. But in spite of this, it's rare when my copy is not only looked over with interest but also taken home by someone who wants to look a bit deeper than the pictures.

Particularly from an audience who are not dedicated stargazers, maybe this says something rather special about the impressiveness of the magazine. More likely though, some of ASTRONOMY's appeal with the photo group can be attributed to the fact that many of its members are ardent nature lovers, and quite naturally, much of their effort is devoted to the many and varied facets of nature photography. Beyond the Sierra Club or Federation of Conservationists, it would be very difficult to find individuals with more concern for nature than these, or who are more appreciative of its beauty in all forms.

The connection between this and astronomy may seem tenuous. But let's face it: The study and love of astronomy and the study and love of nature are equal and inseparable.

Consider the sky for a moment. If only by virtue of its overwhelming size, isn't this world above a prime candidate for study by anyone with even a passing interest in the rest of the world around him? It is so unfortunate that many people, unaware of the natural beauty surrounding them, fail to recognize it and consequently miss much of the enjoyment of the beautiful things that contribute to a rich and fulfilling life.

Gauging audience reaction to nature programs, many individuals express what could only be called amazement at the beauty and intricate interrelationships inherent in even the most simple natural things — many of which they have been walking by all their lives without seeing. As for astronomy, the dust they kick up with their feet blinds most people to nature's beauty in the sky above them.

Astronomy is the most exciting, beautiful and challenging of all the fields of nature. Time spent with the sky can be abundantly rewarding for anyone with the eyes to see and the mind to inquire. This can be just as true even if that seeing is coupled with only a basic knowledge of the subject. It's very easy to completely forget the clock, then suddenly realize it's 3:30 a.m. and work starts in 4-1/2 hours.

Certainly, observing something as it appears in the sky can be an emotionally uplifting encounter with nature, and very few astronomy enthusiasts would disagree. But studying the same thing as it appears on film can also be the source of both fascination and wonder. So often the visual provides only a ghost image of what is there. It seems inconceivable how anyone could look and not be driven by simple curiosity, if nothing else, to want to learn more.

To look at an object directly through the telescope, then know the direct personal involvement required to photograph it, and finally have your own photo to compare with visual impressions — this can also be a uniquely special experience.

It doesn't matter that the observatory photo in the textbook shows much more detail. It is the almost impossible-to-describe feeling of having developed a oneness with what's up there — like being on an intimate first name basis with the heavens — that gives your total involvement with nature through astronomy its meaning.

Yes, it's easy to look at these things with entirely too much emotion and not nearly enough scientific objectivity. But should this be a totally uncommon attitude? If it should be, then we — Sharon and I — are the only women astrophotographers among ASTRONOMY's readership.

As for me, I'm not at all hesitant to express my emotional involvement with astronomy nor the technical, photographic skill that all the more intensifies my enjoyment and appreciation of nature. The black and white photographs included here were made the night of Sept. 6-7. This was a particularly beautiful, enjoyable space of hours last fall — spent first in a photo session, and then in a leisurely hour or so just rambling through one of my favorite parts of the sky with the telescope. The camera was a 5.5 inch Celestron Schmidt (f/1.65) piggyback mounted on the telescope. Exposures were 20 minutes using a Kodak #24R Gelatine filter with 103aE film.

The photograph on the preceding page shows nebulosity in central Cygnus surrounding Gamma Cygni — the bright star near the center of the photo. This area is a rich and lovely part of the Milky Way that reveals its intricacies dramatically using a red filter. The camera filmholder was turned 90 degrees to record the same region in a different format for the top photo on the facing page. An unseen satellite left evidence of its passage across the sky as a streak on the negative.

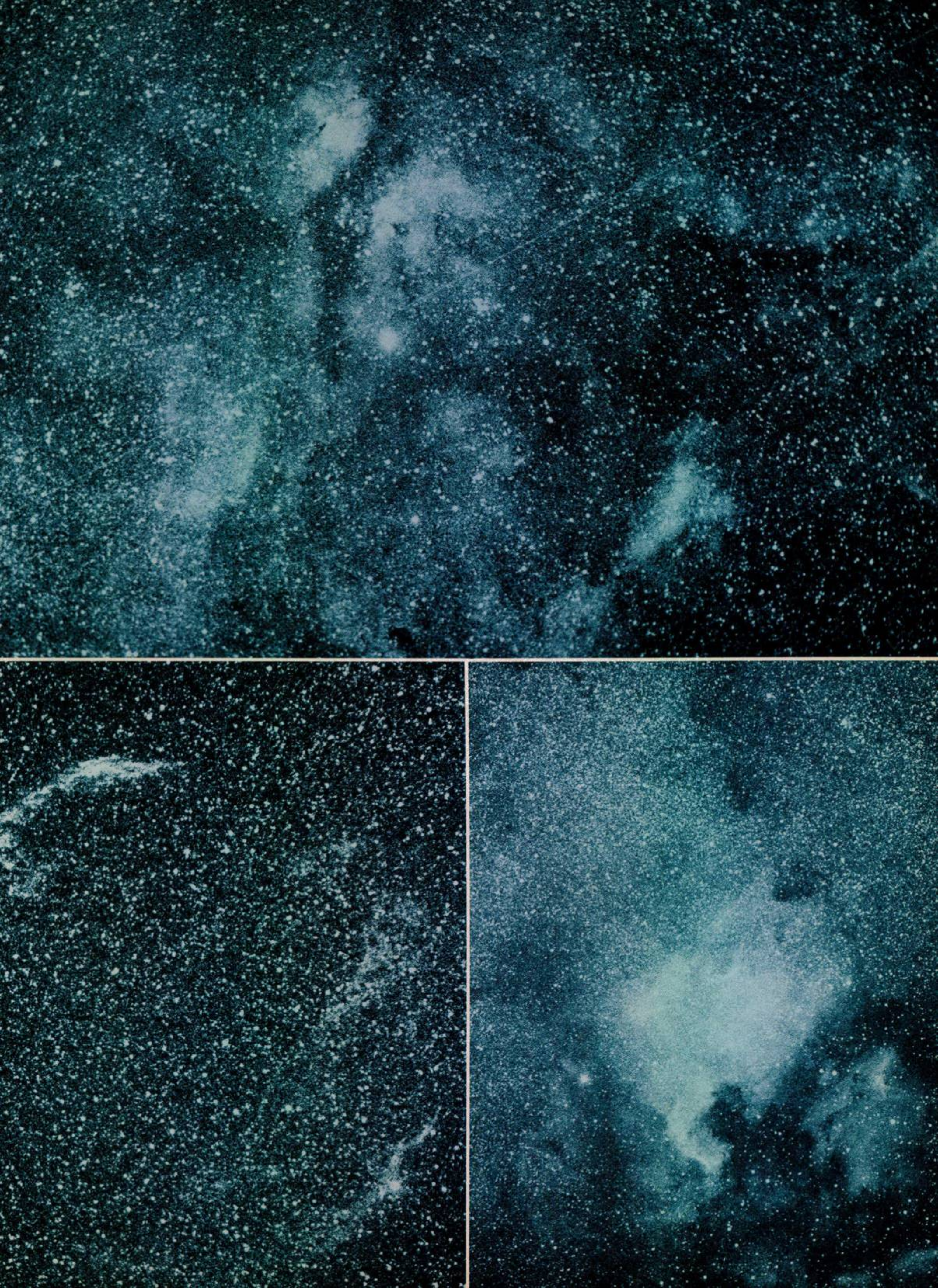
Personal preference is revealed with my cropping of the North American and Pelican nebulae (facing page, bottom left). Most photographers include only the nebula alone. The incredibly dense bright area extending away from "North America", and the dark rifts and background darkness, seem to better capture the feeling of deep sky.

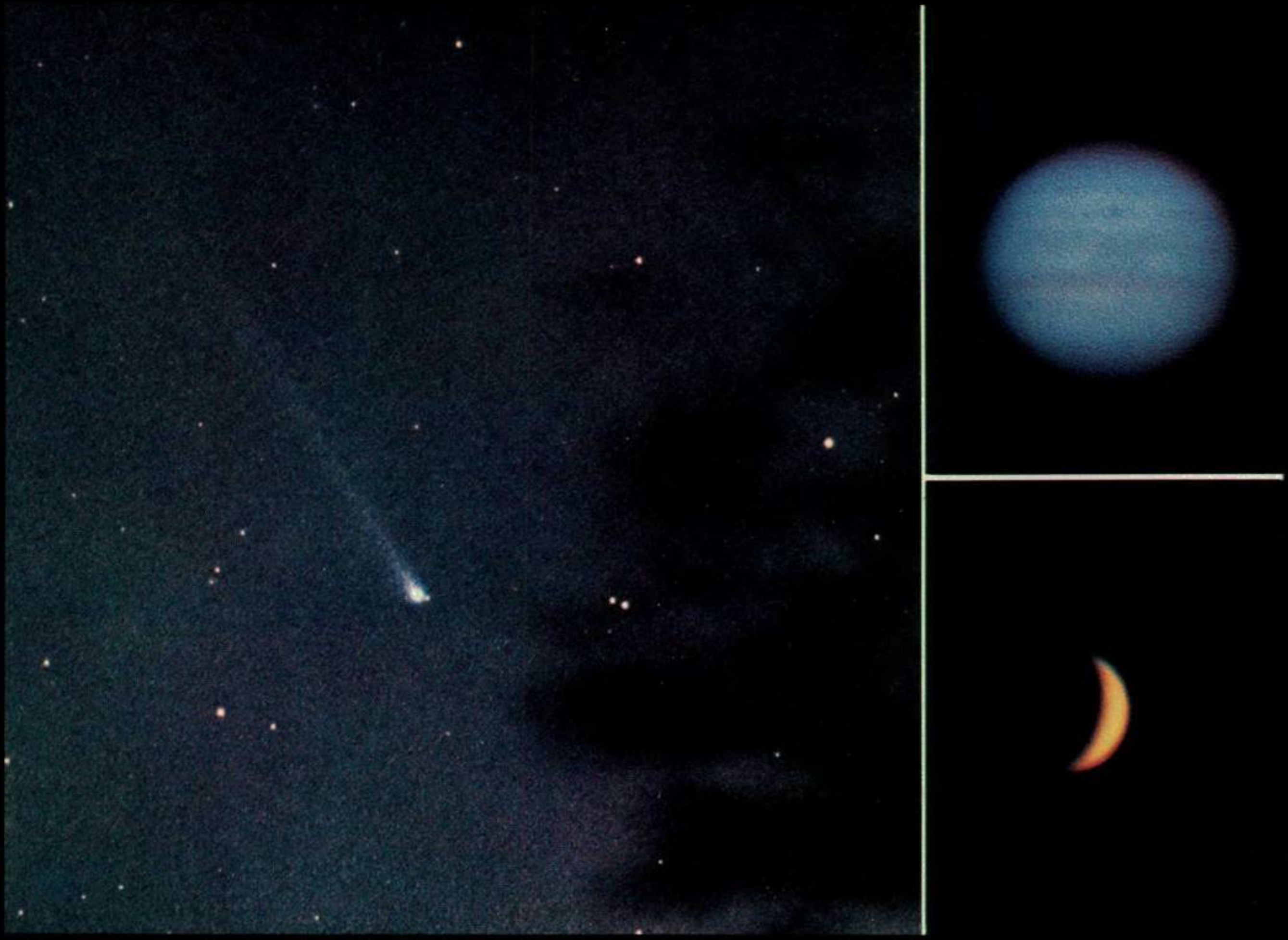
Next to the North American nebula, my choice of film and red filter combination for the Cygnus loop probably leaves something to be desired for this subject. 103aF film — unfiltered or with only a light yellow filter — is better able to record the nebula's predominant blue color along with the red. Past experience with this combination hasn't been too successful from my location because the light pollution level is too high.

The color photograph of comet Kobayashi-Berger-Milon (page 36) was originally from a GAF 200 transparency developed normally in GAF chemistry. I then printed the transparency directly on Cibachrome, a comparitively new print-from-slide process that is very appropriate for home darkrooms where the capability for color print processing is otherwise impossible or limited at best. By increasing development time 30 seconds beyond normal, contrast was increased from the original transparency to an equivalent of about one paper grade in black and white printing. This contrast increasing procedure is a nice feature of this new process making it particularly applicable to astronomical subjects where detail is often tenuous.

True, it wouln't win praise as the world's most detailed comet photo. It does, however, capture perfectly my impression of this delicate celestial wanderer.

My observing site lies in the center of a 2-1/2 acre field bordered on three sides by woods and a hedgerow on the fourth — a very peaceful and pleasant spot. It was from here that I watched the comet many times, appearing adrift among a sprinkling of stars and falling slowly toward the tree-





Comet Kobayashi-Berger-Milon, in Ursa Major at magnitude 4.5, is the brightest object in the picture. The brightest stars are seventh magnitude and the star near the comet's head is ninth magnitude. Exposure time was 20 minutes. Jupiter and Venus were photographed with the eyepiece projection method. Photographs by Diane L. Payton.

tops and the pale glow at the horizon. Though it looked nearly tail-less in the sky, it is easy to mentally combine that visual impression with the photographic record for the overall "enhanced memory" of Kobayashi-Berger-Milon, stars and trees to show the comet perfectly as I like to remember it.

Planetary photography has been a fairly recent addition to my astrophotographic experience as is perhaps demonstrated by the color photographs of Jupiter and Venus. This is definitely not because of a lack of interest, but simply lack of "how to" information and the confidence that my equipment and I could really produce a planet instead of a blob. In this regard, ASTRONOMY's various articles on astrophotography have been largely instrumental in encouraging me to get out there and shoot. These two slides are among my best to date.

I know I have a long way to go in learning all the technical fine points of planetary photography. Focusing accurately, for example, is still a big problem — even with the matte surface Type D screen in the Nikon camera body. If nothing else, these slides should say that your instructive information is indeed being put to use — and is encouraging readers to expand their horizons.

In closing I just want to add, most sincerely: Thank you for encouraging women to explore the natural beauty of astronomy and for helping us intensify our appreciation of it through the technical extension of astrophotography. Thank you for creating ASTRONOMY, a publication that stands by itself in caring enough to write for all who want to know and want to learn — not in the manner of others whose treatment of the subject is often dry and esoteric, but in a way both beautiful and graphic, both comprehensive and easily comprehensible.

Diane L. Payton is president of an 80 member photography club which belongs to a loose affiliation of nine clubs in western New York state and Ontario (total membership is 700). Her most serious avocations are nature study and photography — topics on which she frequently lectures in her area.

EDITORS NOTE: This article is based exclusively on one letter recently received from Ms. Payton. While it is written in a style contrary to our policy for feature or departmental articles (specifically, use of the first person narrative), her letter so poignantly raises issues we consider important that we have converted the letter into a full fledged article. The editors of ASTRONOMY eagerly seek comments from readers not only on the points Ms. Payton raises, but also your favorable and unfavorable suggestions on the continued though limited use of this narrative form in future issues of the magazine.

Photograph a Comet

by

Leo C. Henzl Jr.

When a new comet appears in the sky, it's inevitable that some enterprising vendor, attuned to popular fear and fable concerning ill effects of cometary gas, will offer placebos of one kind or another in pharmaceutical jars labeled "Comet Pills". Skip these on your next trip to the druggist; but while you're there, why not pick up a few rolls of "Comet Film"?

Local drugstores and photo retailers are sure to have this product in stock, because any reasonably "fast" black and white or color emulsion is suitable for shooting comets. Add a few accouterments of ordinary snapshooting — a 35mm or roll-film camera with time exposure capability and f/2.8 or "faster" lens, a tripod and a locking cable release — and you have all the equipment you'll need to capture comets (and a variety of other celestial objects as well).

If you can see a comet, you can photograph it. Here is what's involved:

1) Set your lens wide open for full aperture and infinity focus.

2) Set your shutter for a time exposure ("T" or "B" position on the indicator dial).

3) Frame the comet and star field in the viewfinder, including in your composition scenic foreground material if possible.

4) Lock open your camera shutter long enough to record the comet, but not so long that background stars are rendered as trails.

Of these four steps, only the last — exposure — is likely to pose any particular obstacle to success. How *long* is *long enough*? This depends on the focal length of your lens and the declination (or celestial latitude) of the comet. With the normal 50mm focal length lenses on most 35mm cameras, the approximate exposure limits for pointlike star images are as follows:

Declination	Exposure Time
60° to 90°	30 sec. to 45 sec.
30° to 60°	20 sec. to 30 sec.
0° to 30°	10 sec. to 15 sec.

For longer or shorter focal lengths — lenses other than the 50mm used in this example — exposure limits are in simple inverse proportion. With a 28mm wide-angle lens, for example, you can just

SECONDS OF EXPOSURE BY FOCAL LENGTH & DECLINATION

	f.l. in mm's	28	35	40	50	55	58	75	80	135
Exposure Range at Declination	60°to 90°	54-80	43-64	37-56	30-45	27-41	26-39	20-30	19-28	11-17
	30°to 60°	36-54	29-43	25-37	20-30	18-27	17-26	13-20	12-19	7-11
	0°to 30°	18-27	14-21	12-19	10-15	9-14	8-13	7-10	6-9	4-6

Highest figure in ranges usually results in some trailing of stars.

about double exposure times; with a 135mm telephoto, a reduction to the ratio of 50/135 is required. Some experimentation is recommended here, as the amount of tolerable star trailing is up to your own judgement. How much trailing of the star images is esthetically acceptable to you? You may wish to sacrifice some stellar image sharpness to record additional extent of the comet's tail with longer exposure times.

The greatest exposure you can use is limited by the speed (f/ratio) of your camera lens and the "motion" of the stars due to Earth's rotation. So obviously, it pays to use the fastest film available. Among color slide films, Kodak High-Speed Ektachrome (ASA 160), Fujichrome R-100, GAF 200 and GAF 500 are excellent performers. (For additional information, see "What Color Slide Film Should I Use?", ASTRONOMY, October 1974.) For black and white photography, Kodak Plus-X (ASA 125), Tri-X (ASA 400) and 2475 Recording Film (ASA 1000+, precise speed dependent on processing) are proven performers. Commercial black and white processing is traditionally mediocre and simply won't yield the contrast necessary for satisfactory prints. So, unless you're prepared to do your own processing, color films will prove to be the more satisfactory choice. There is little advantage (other than satisfaction and economy) in processing color films at home.

Beware! When using color transparency films for any astronomical purpose, always employ the first frame to shoot an ordinary, easily identified, terrestrial subject. This averts the potential disaster that occurs all too often when a color lab, unable to distinguish between subject matter and unexposed film separating frames, guesses at frame location and allows the automatic film cutter to chop your sky photos into random bits!

No matter how fast the film and lens, a stationary camera's limitations will result in a cometary image that is essentially underexposed. That is, though the portrait may be a rewarding facsimile of the comet's visual appearance, longer exposure would certainly disclose tail structure many times the extent visible to the unaided eye.

This is where guided astrophotography (and more sophisticated equipment) will be required. Mount your camera piggyback to an equatorial clock-driven telescope. This permits exposure times that are long enough to record the comet's dim outer reaches. Your only limits here to long, guided photographs are those imposed by the relative darkness of the sky at your shooting site and the comet's own proper motion against the fixed stellar background.

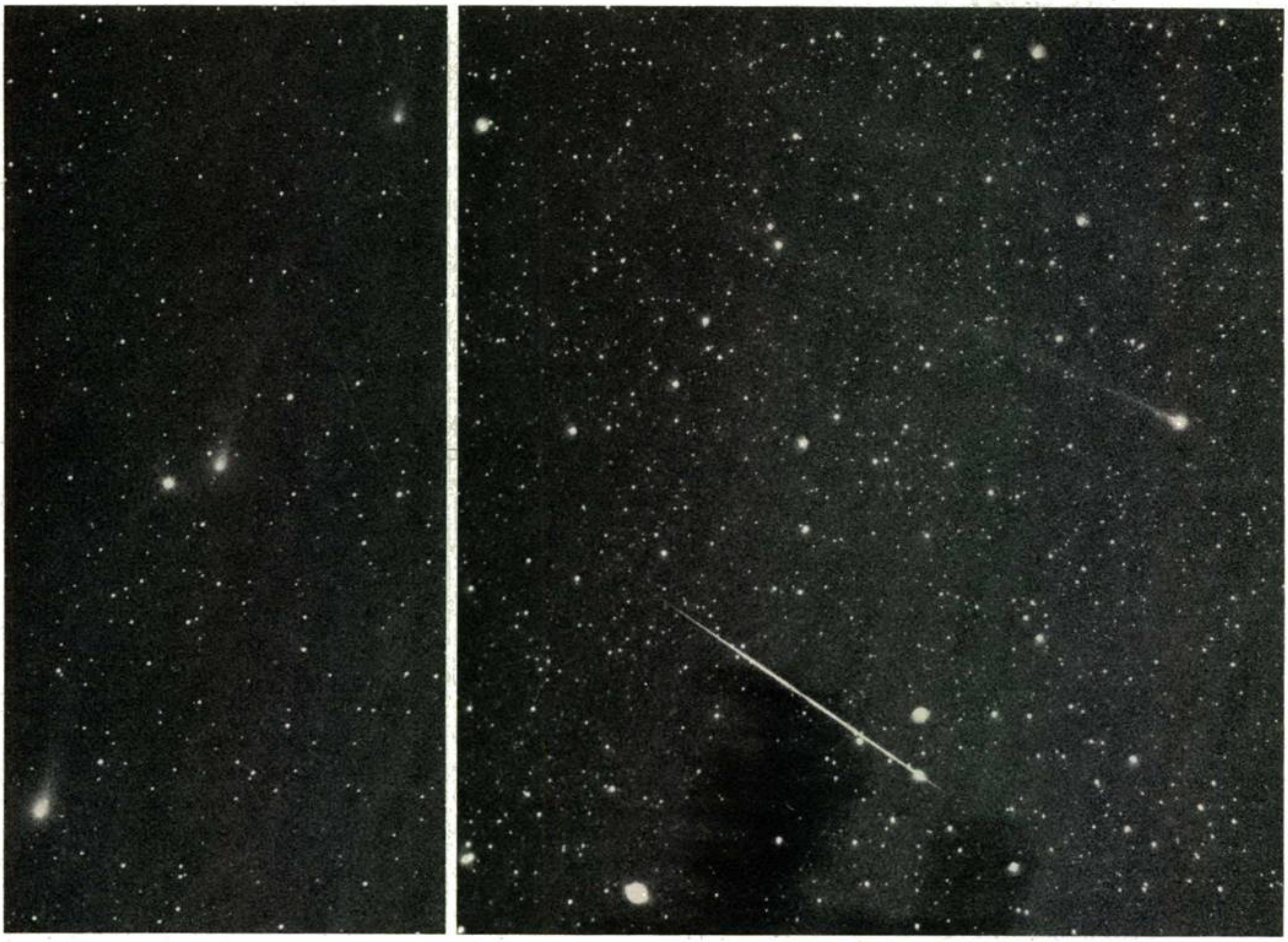
For city or near metropolitan dwellers, a bright, light polluted sky is the greatest limitation. But even if you have less than favorable sky conditions, all is not lost. It's easy to establish a *sky fog limit* in advance of a comet's arrival by making a series of bracketed exposures. With a stationary camera pointed toward the area of the sky where predictions indicate the comet will be best placed for photography, make an exposure series of 5, 10, 15 and 20 minutes each at f/2.8. The ideal exposure duration for you is just shy of the point where scattered sky light begins to fog out the faintest star trails.

If the comet had no proper motion of its own, you could make guided exposures reaching your sky fog limit in order to record the greatest possible amount of detail and extent with a given combination of lens and film. But comets move — frequently more than 10 degrees per day near perihelion, when they're brightest. This translates into motion of 25 seconds of arc or more per minute of exposure time — enough motion to be resolved in only a few minutes by a high quality 50mm camera lens. So even with your camera clock-driven, fairly brief exposures are necessary if you wish to photograph both comet and stellar backdrop without hopelessly blurring intricate cometary structure. In spite of this, however, because comets are diffuse in the first place, several-minute exposures with fast telephoto systems and medium focal length camera lenses are often practical. As a result, the combination of fast film and extreme speed optics allows exposures that let you approach the sky fog limit for your astrophotography site. And a picture of a comet, though imperfectly rendered, against a sharply defined field of stars is a compelling portrait indeed.

Piggyback comet photography with very long focal length camera lenses, or even through telescopes, records only a portion of a particularly bright comet. Dark-site photos of comet Kobayashi-Berger-Milon (1975h), for example, show a tail spanning nearly 15 degrees of sky, so the subject simply didn't "fit" a 35mm frame through a lens of more than 135mm focal length. The purpose,then, of photography with longer optics is to capture maximum detail within the comet's nucleus, coma and inner tail. For this task, the camera must track the comet itself, rather than the sky. The net result is a sharply defined comet against a background of stellar streaks.

Tracking a comet for a long exposure is a tricky business. Ordinarily, in guided photography, you center illuminated crosshairs of a high power guiding ocular against the image of a star near the photo-

A comet is faint and easily lost in light pollution or sunset glow; a sky fog limit should be established to determine the duration of exposure. These views of comet Kohoutek show the effects of sky fog. At upper left, in a 90 second exposure taken an hour after sunset, the comet stands out against a nearly blank washed out background. More stars are visible at upper right, two hours after sunset, in a 45 second exposure. In another photo taken two hours after sunset, exposure time is 10 seconds and less background detail is seen. A five minute exposure at lower right shows the comet against a sky with little fogging. Upper left: Photograph by Steve Rismiller; Right: Photograph by Thomas C. Peterson. Lower left: Photograph by Larry Imperiale; Right: Photograph by Ewell Schirmer.



Of the two objects apparently streaking across the sky in the photograph at right, only the bright meteor actually did so. The other is comet Kobayashi-Berger-Milon, captured in this seven minute exposure with a 58mm lens at f/1.4. Comets have motion of their own, as demonstrated by the superimposed photos at left taken of comet Kohoutek on Oct. 29, 30 and 31, 1973. Left: Lunar and Planetary Observatory photograph. Right: Photograph by Larry King.

graphic target (the guide star). With the aid of a drive corrector and precise declination control, you strive to keep the sharply defined stellar image centered for the duration of the exposure. If your telescope mount is accurately aligned with the celestial pole, declination corrections are infrequent, and a successfully guided photo hinges mostly on your skill in using the drive corrector to undo vagaries of clock drive and atmosphere. In general, to detect errors before they record on film, the greater the guiding magnification, the better.

Long exposure comet tracking is tricky, however, as it presents no sharply defined point as a guiding reference, and its proper motion is as likely to carry it across the sky in declination as in right ascension. Fortunately, the nucleus of a comet often looks starlike at modest visual magnifications, so guiding may prove easier with a lower power guiding ocular than customary. Again, owing to the diffuse nature of the subject, a slight guiding error on the comet itself isn't likely to prove noticeable. Highly objectionable, however, are background star trails displaying the symmetry of a drunkard's stroll. The ideal photo will show background stars as pleasingly straight lines.

The few days of a comet's favorable appearance are no time to practice this difficult art of guiding, so why not contrive a similar set of conditions in advance? Try deliberately misaligning your polar axis a few degrees and running your clock drive perhaps five percent slow or fast. Then choose a fixed stellar object of cometlike appearance. The Great Andromeda galaxy (M-31) is ideal. If you're successful in guiding perfectly on this (or a similar) object, stars away from the center of your photographic field will look like symmetrical arcs due to the field rotation that occurs with a grossly misaligned telescope. This may take quite a few trial runs to achieve, but it's doubtful you'll begrudge the effort when it's time to go after the real thing.

There is no such creature as an ideal comet photo. A simple stationary camera snapshot of a comet poised over the skyline of a city or mirrored in a lake; a piggyback photo of this celestial trespasser buried among the star clouds of the Milky Way; an elaborately guided portrait of the delicate rays and filaments expelled from the nucleus — each has its own special appeal. Use what you have to best advantage, and a visiting comet is sure to add a few treasures to your photo collection.

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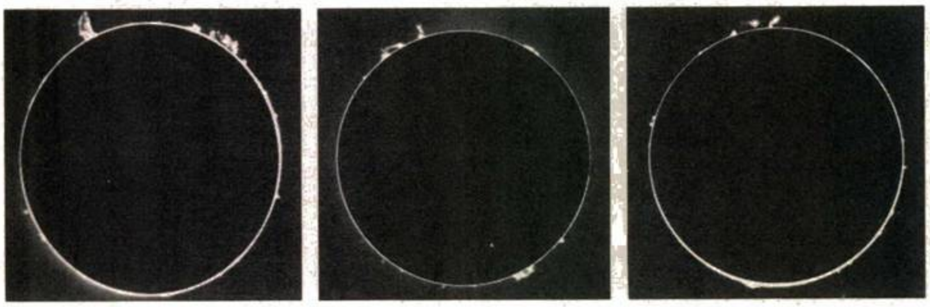

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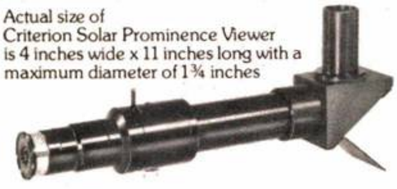

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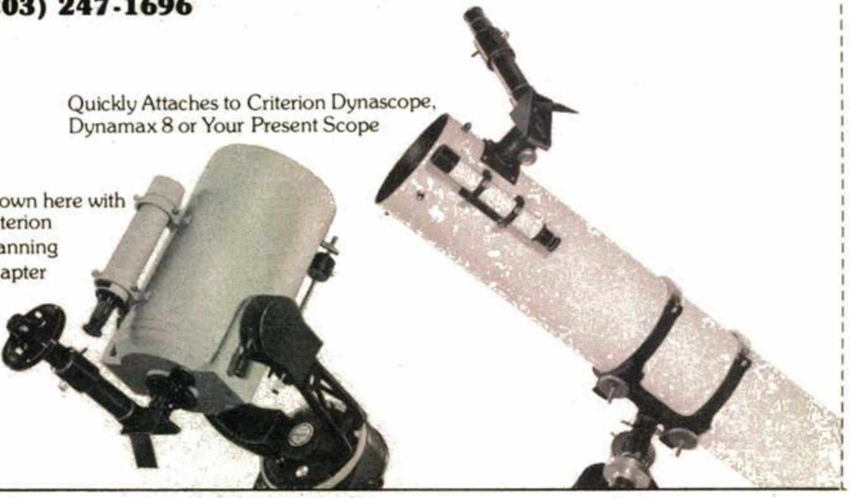

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GAZER'S GAZETTE

The Gibbous Moon

by

Henry J. Phillips

It is odd but true that as the moon progresses from half to full phase, it grows increasingly difficult to observe. Naturally it is larger and brighter with each successive night, but as we move away from the *terminator* (the dividing line between the lit and unlit portions of the moon), the details on the surface become almost impossible to discern. Craters turn to flat, featureless rings; mountains lose the appearance of great height lent them by their shadows; even the maria are not as sharply defined against the background glare.

Close to and along the terminator, however, the view is much more rewarding. When the moon is in its *gibbous* phase (the word gibbous is from the Latin meaning "hump" — referring to the moon's lopsided shape at this time), some of its most interesting and prominent features move into view; their splendor amply compensates for the growing disappointment we may feel with objects we have studied during the moon's earlier phases.

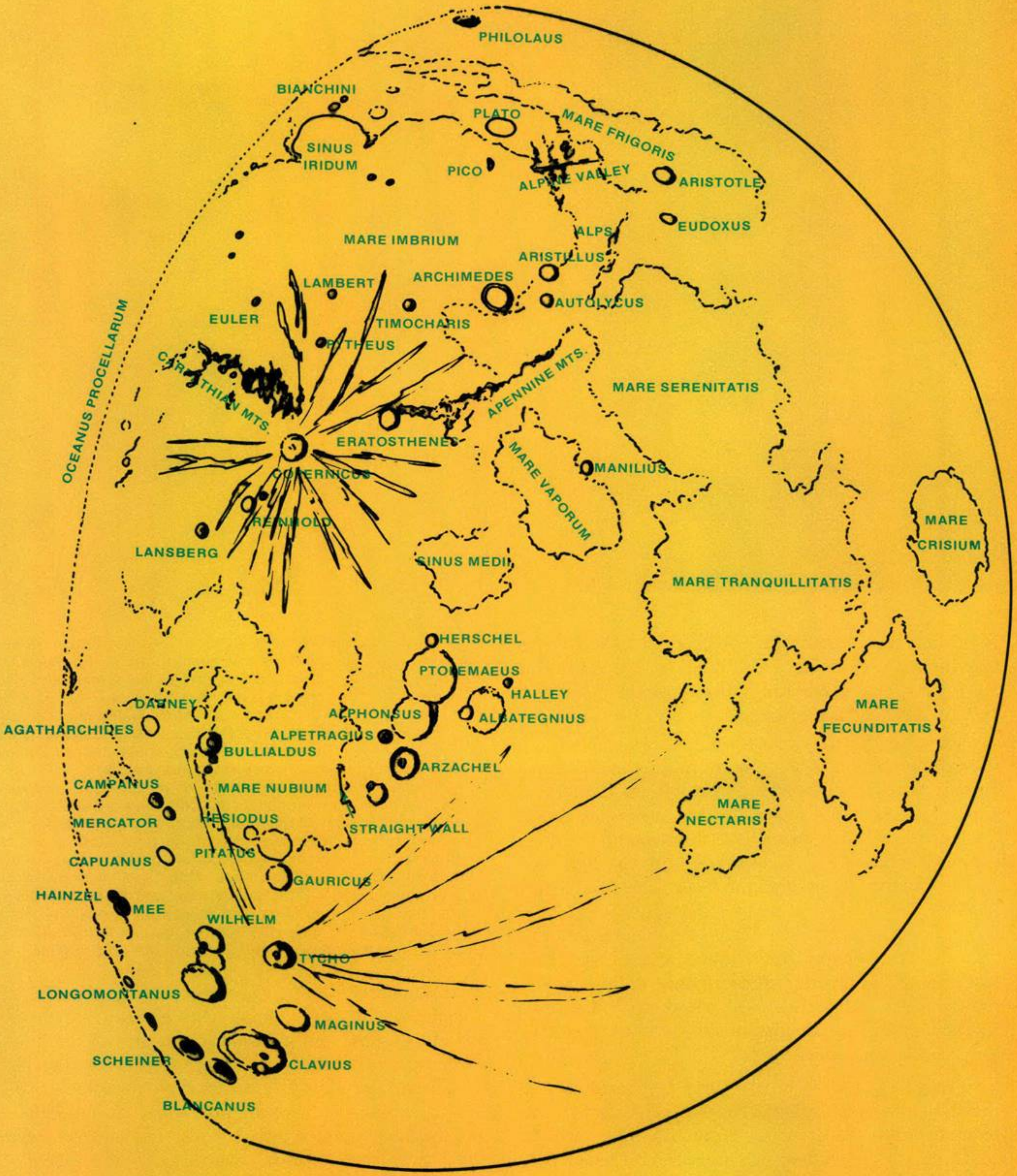
Craters always have a more dramatic appearance when dawn is breaking over their walls; the shadows that creep along the crater rings and floors point up a fantastic amount of detail. When the moon is about 10 days old (halfway between first quarter and full), this fact is brought home by the jumbled mass of craters we see near the south pole. The most prominent of these is Tycho, probably the best known feature of the lunar surface. Later, when the moon is full, Tycho's system of rays will dominate the entire surface of our satellite. But during the gibbous phase we can give more attention to the crater itself — and it is a magnificent one. The slightest visual aid — even binoculars — will show Tycho's central peak, situated almost in the exact center of the nearly circular walls. You can see the details of Tycho's high terraced walls in a four inch telescope, and larger apertures will make them more obvious. Such views emphasize the fact that everything about Tycho must be expressed in superlatives.

This is also very nearly true of Tycho's neighbor to the south, the giant walled plain Clavius. Second largest single crater on the moon, it extends 145 miles from one side to the other and could hold the entire country of Switzerland within its bounds. Clavius is obviously a much older crater than Tycho, for smaller, more recent formations are scattered across its surface — in some places even interrupting the large crater's walls.

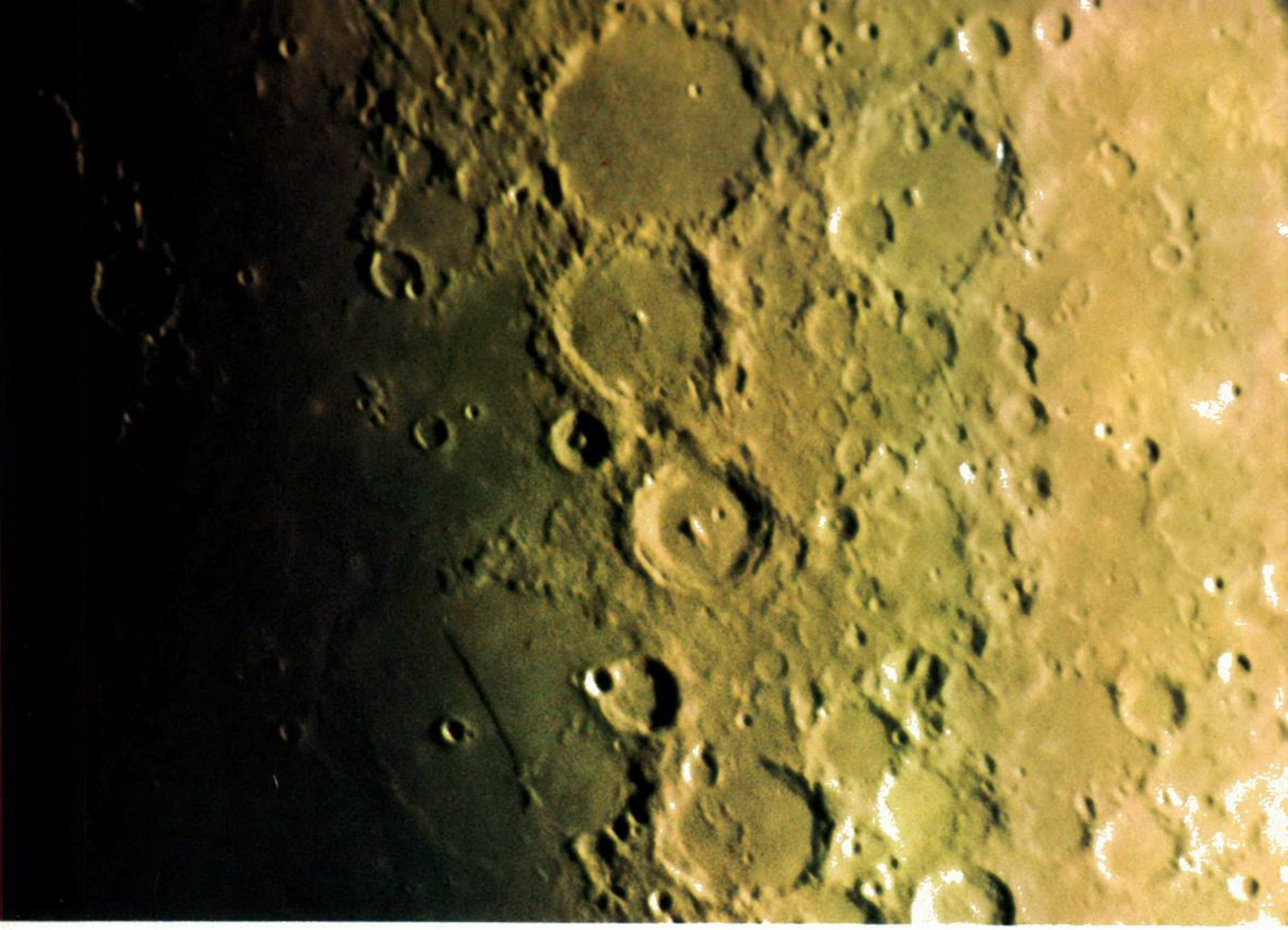
Because it is so near the moon's edge, our view of Clavius is an extremely foreshortened one; it provides an excellent example of the effects of *libration.* This is a slight swinging motion caused by the eccentricity of the moon's orbit and the tilt of its axis. As a result of this motion, we can see features near the moon's limb in slightly different aspects during each cycle of phases. Try sketching or photographing Clavius during two different cycles; differences between the two will be obvious.

There are several other notable craters in this extremely rugged area. Tycho is part of a rough quadrilateral that contains three other large craters:

When the moon is about 10 days old, some of its most spectacular features swing into view — including the great ray systems of Tycho and Copernicus. Note especially the brightly lit walls of Sinus Iridum, near the northern end of the terminator. A Celestron 8 Schmidt-Cassegrain was used for this 1/8 second exposure on Kodak Kodachrome II film. Photograph by John Sanford.


PHILOLAUS
BIANCHINI
PLATO
MARE FRIGORIS
SINUS IRIDUM
PICO
ALPINE VALLEY
ARISTOTLE
EUDOXUS
ALPS
MARE IMBRIUM
ARISTILLUS
ARCHIMEDES
LAMBERT
AUTOLYCUS
EULER
TIMOCHARIS
PYTHEUS
OCEANUS PROCELLARUM
CARPATHIAN MTS.
APENNINE MTS.
MARE SERENITATIS
ERATOSTHENES
COPERNICUS
MARE VAPORUM
MANILIUS
MARE CRISIUM
REINHOLD
LANSBERG
SINUS MEDII
MARE TRANQUILLITATIS
HERSCHEL
PTOLEMAEUS
HALLEY
DARNEY
AGATHARCHIDES
ALPHONSUS
ALBATEGNIUS
MARE FECUNDITATIS
ALPETRAGIUS
BULLIALDUS
ARZACHEL
CAMPANUS
MARE NUBIUM
MARE NECTARIS
MERCATOR
HESIODUS
STRAIGHT WALL
CAPUANUS
PITATUS
GAURICUS
HAINZEL
MEE
WILHELM
TYCHO
LONGOMONTANUS
MAGINUS
SCHEINER
CLAVIUS
BLANCANUS

Lick Observatory photograph/Artwork by Victor Costanzo.



Maginus, Longomontanus (both nearly as large as Clavius), and Wilhelm which is about the same size as Tycho. All three are quite prominent on the pockmarked surface of this section of the moon.

Moving north, we encounter Mare Nubium, the farthest south of the moon's major "seas". Mare Nubium does not have the well-defined borders of some of the other maria and it rather straggles across the area that it does cover. But there are many interesting objects along its edges — not the least exciting of which is the Straight Wall. This is a nearly straight ridge some 60 miles long, the western side of which is about 800 feet higher than the ground to the east. It lies along the western edge of the Mare Nubium; although not quite visible in binoculars, the smallest telescopes will show its threadlike shadow, and in larger instruments you can see this long escarpment quite well.

Three large craters are lined up northwest of the Straight Wall outside the Mare: Arzachel, Alphonsus and Ptolemaeus. Arzachel, the farthest south, is a ring plain with a high central peak, near which is located a deep craterlet in Arzachel's floor. Separated from Arzachel by a few miles of mountainous terrain is Alphonsus, which also has a central peak,besides several furrows and discolored patches running along its floor. Alphonsus was the center of some controversy in 1958 when Soviet astronomer Nikolai Kozyrev, using the 50 inch reflector at the Crimea Observatory, reported a reddish glow and an emission of gas at the base of the central mountain. Earlier observers had noted such a faint glow but others have detected nothing, and Alphonsus has remained quiet throughout subsequent diligent study. Finally, Ptolemaeus, largest of these three craters, is a rather badly eroded one with lower walls and a smoother central plain than the others. An observer in the middle of Ptolemaeus would be unable to detect the outer walls due to the closeness of the horizon, and there are gaps through which someone could walk without finding it necessary to do any climbing.

In the photograph above, a six inch Cave Newtonian recorded the Straight Wall and the surrounding area. The three large craters (top to bottom) are Arzachel, Alphonsus and Ptolemaeus. On the opposite page, top left photo, the dark floor of Plato is shown in marked contrast to nearby Mare Imbrium; to the south are Mount Pico, the Teneriffe Mountains, and the Straight Range. Both this and the accompanying shot below it of Copernicus are 3/4 second exposures on Plus-X film at f/83, taken through an eight inch home built Newtonian reflector. The deeply terraced walls of Copernicus are visible, as well as a great number of tiny craterlets to the east. Moving south along the terminator as shown in the right hand photograph, the region of Tycho and Clavius is one of the most rugged and forbidding on the lunar surface. This 2-1/2 second exposure was made using a dark yellow filter and Kodak Verichrome Pan film through an eight inch Celestron. Above: Photograph by John Sanford. Opposite, top and bottom left: Photographs by Howard Zeh; Right: Photograph by Martin Germano.

In the eastern part of Mare Nubium, opposite the Straight Wall, is the bright crater Bullialdus; it is of the same species as Tycho with a high central peak and circular terraced walls. Just north of the Mare we can find Fra Mauro, near which the Apollo 14 mission landed in early February 1972. This hilly region forms an enclave into the Mare; without this interruption, the lava field would run straight through to the crater Copernicus.

Copernicus dominates its area just as thoroughly as does Tycho farther south. It is almost the same size as Tycho — 56 miles across to Tycho's 54 — and has the same high, terraced walls and prominent ray system. The only major difference between the two is Copernicus' lack of a major mountain within its walls — although it does contain several smaller ones.

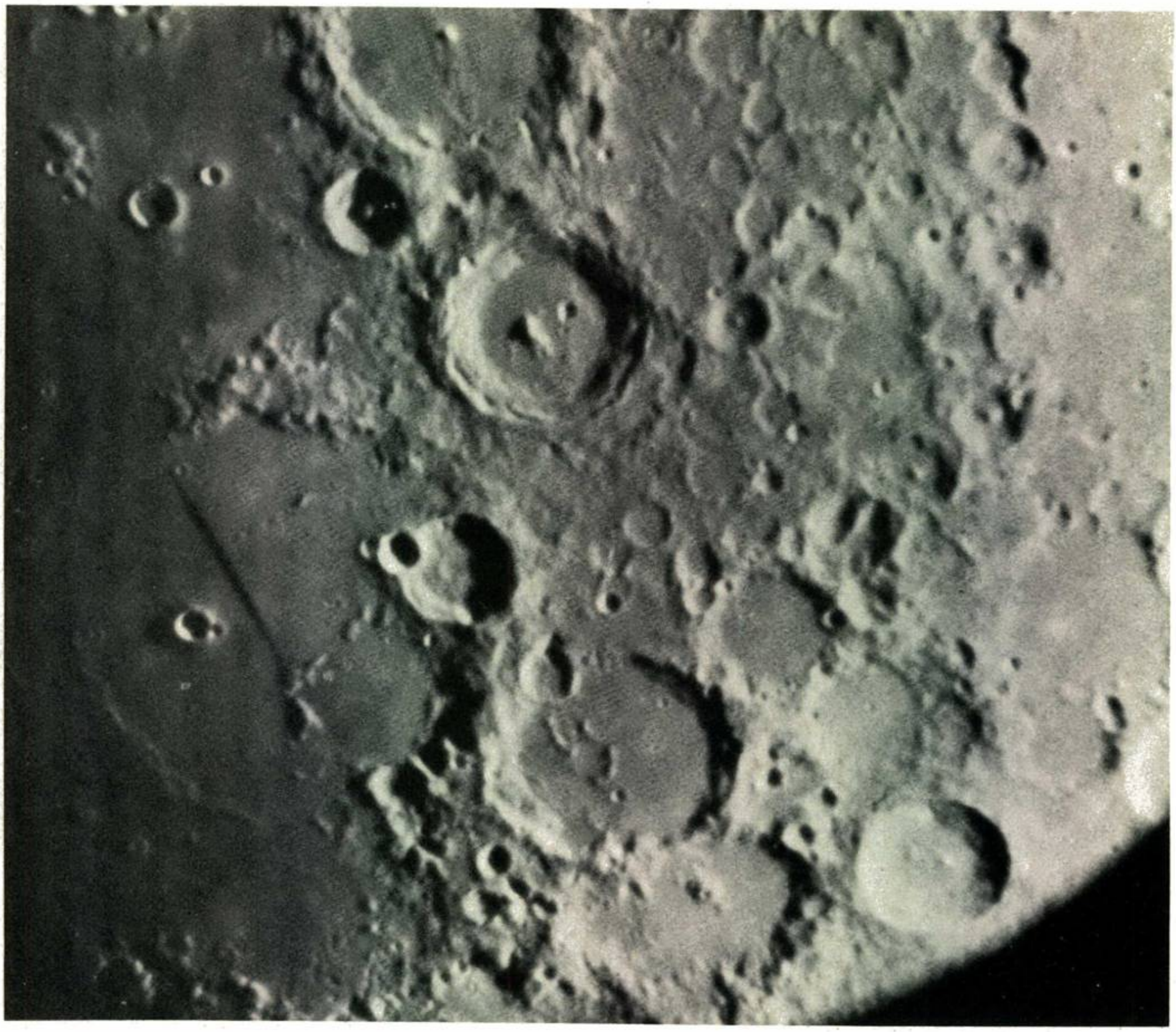
During the gibbous phase, the rays of Copernicus are much more noticeable than those of Tycho at the same time. Tycho's rays are the glory of the full moon, when they spread across almost the entire face of the lunar surface. Copernicus' rays are not as long; they do not extend past the marelike area in which Copernicus is located, but they are more closely packed around the crater and — at the 10 day old phase — are as bright as Tycho's.

Several miles northwest of Copernicus is its "little brother" Eratosthenes. Similar in most respects to its larger neighbor, Eratosthenes has a central peak topped with a craterlet of its own. This is visible under good conditions with a 2.4 inch aperture telescope; larger instruments show it perched atop its mountain and almost giving it the look of an overturned funnel.

Reinhold and Lansberg are two more craters visible southeast of Copernicus, with Lansberg containing a bright central peak. They are comparatively small but easily found, being placed in a smooth area; if they were near Tycho, they would be virtually indistinguishable from others just like them.

Eratosthenes is located at the eastern end of the Apennines, the most spectacular mountain range on the moon. With the Carpathians north of Copernicus, the range forms the southern boundary of Mare Imbrium, one of the finest and most extensive of the maria. Perhaps the smoothest of all the lava fields, it is almost completely free of the large craters which dot other maria, and most of the prominent features in this area are situated along its edges.

At the western side of the Mare, near a small bay named Palus Putredinus (Marsh of Decay), lies Archimedes, a walled plain with well-defined borders and a smooth lava floor. Two very deep craters, Aristillus and Autolycus, can be found just to the west of Archimedes; when exactly on the



The above photograph shows much of the detail visible in a six inch reflector of the area at the western edge of the Mare Nubium. Nights of good seeing will highlight some details more sharply. Photograph by Tim Tomljanovich.

terminator, they look like two shining doughnuts on the edge of the moon, as their floors are completely in shadow.

Like a sentinel pointing the way, the solitary Mount Pico stands half-drowned in the Mare Imbrium, just south of the great crater Plato. The same catastrophe that formed the great lava fields of the Mare flooded this 60 mile wide crater, which is now one of the darkest spots on the moon. Compare its floor with that of Archimedes; although both contain smooth plains of frozen lava, the difference in brightness between the two is striking. You will probably need at least 10 inches of aperture to study the tiny craterlets and color variations in the floor, but with any optical aid, Plato is an interesting sight.

The lava flows that filled Plato at least left its walls intact. This was not the case with another formation to the east — the Sinus Iridum. In its present form, the Bay of Rainbows is an offshoot of Mare Imbrium. But apparently before the Mare was formed, this was an extensive walled plain much larger than Clavius. When the Mare was created, the southern wall of this crater was broken down — inundating it with lava and reducing it to no more than a bay of the larger "sea" nearby. Its circular form can still be detected; the outer wall is now known as the Jura mountain range. When the Sinus is just coming into the daylight, the Juras are brightly lit while the bay itself remains in shadow — giving this area the appearance of a diamond necklace reaching out from the Mare Imbrium into nearby blackness.

The moon can be studied in more detail than any other celestial object. There is no end to the number of breathtaking sights visible on its surface and changing in appearance daily, and every observing session can reveal something new. Be grateful for the moon, not merely for the reasons of its causing tides and solar eclipses, but for the sheer visual beauty it provides.

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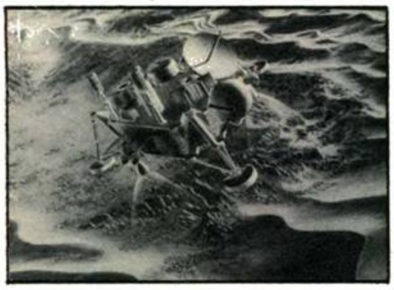

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continued on page 56

Comet West Brightens

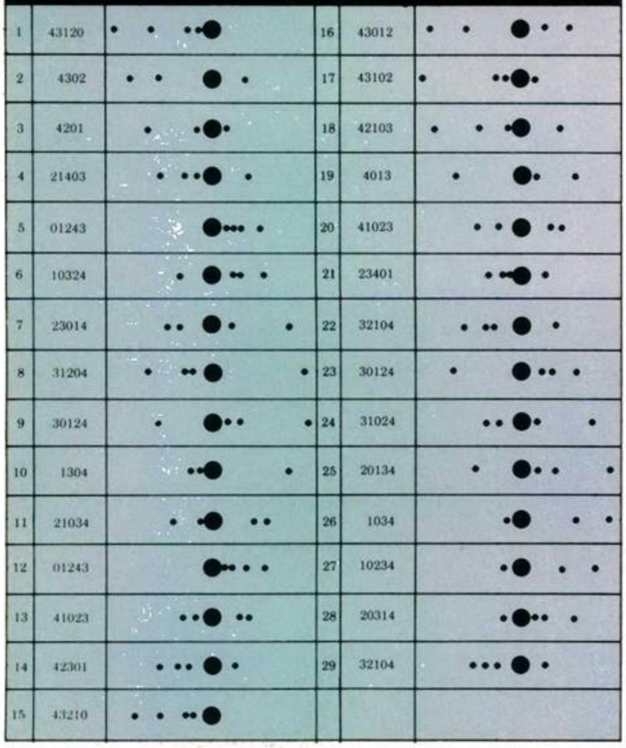
The brightest planets are still visible in the evening sky this month, but time is running short; February will be the last month for some time during which Jupiter is high above the horizon. Mars and Saturn also are slowly abandoning the sky; by the middle of spring the field will have been left clear for the much dimmer, outer planets.

Comet West (1975n)

Comet West will reach perihelion on Feb. 25, and presstime predictions hold out hope that it will be a bright and rewarding sight in the morning sky a few days later. However, comets are noted for their unpredictability; due caution should be taken against the possibility that comet West may be as much of a disappointment as the infamous Kohoutek of 1974.

FEBRUARY SATELLITES OF JUPITER

9:30 p.m. EST, 6:30 p.m. PST



1	43120	16	43012
2	4302	17	43102
3	4201	18	42103
4	21403	19	4013
5	01243	20	41023
6	10324	21	23401
7	23014	22	32104
8	31204	23	30124
9	30124	24	31024
10	1304	25	20134
11	21034	26	1034
12	01243	27	10234
13	41023	28	20314
14	42301	29	32104
15	43210		

Jupiter's four largest moons are so bright you can see them easily in even the smallest telescope. Orbiting swiftly around Jupiter in 2 to 17 days, their positions as viewed in a telescope change from night to night. Sometimes, especially when two moons are close to each other, their motions become evident with only a few minutes' observation. Eastern and Pacific Times are provided; subract one hour for Central Time, and add one hour for Mountain Time. First column (left) gives dates; second, the moons relative to Jupiter (1=Io, 2=Europa, 3=Ganymede, 4=Callisto, 0=Jupiter's disk); third, the approximate positions of the moons as seen in an "inverted image".

If things work out for the best, the comet should extend brightly several degrees above the horizon just before sunrise on the 29th. It will sweep with increasing speed through the constellations Aquarius and Pegasus during the mornings of early March (see the accompanying diagram). As comet West rises earlier each morning, the sky background against which it appears will be progressively darker, thus compensating to some extent for the loss of magnitude it suffers as it races away from the sun.

If West does not reach its predicted brightness, finding it may be a challenge. Depending on its actual magnitude, you may be able to pick it out with the naked eye if you look closely. But your best bet will probably be binoculars or a small telescope.

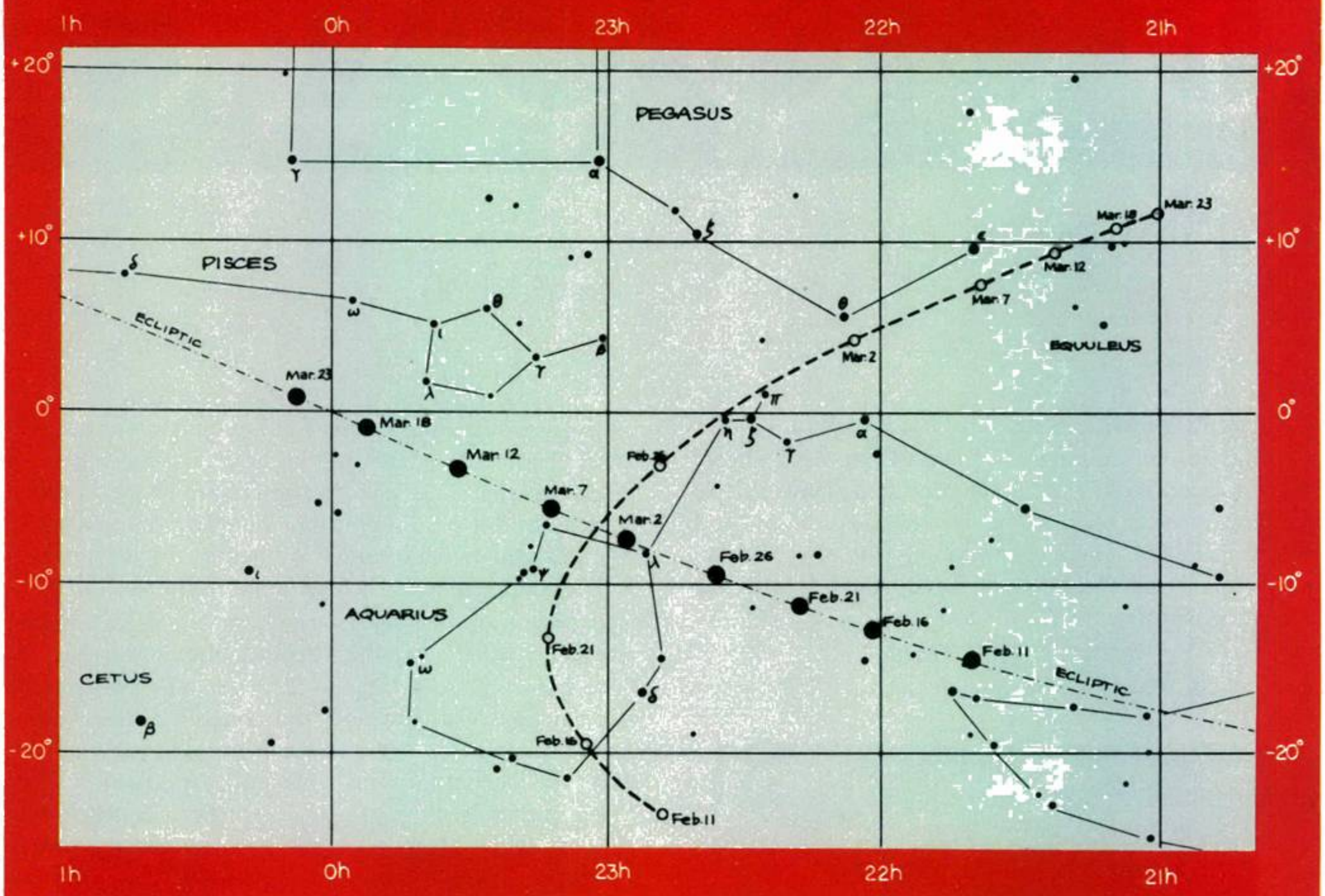
Mercury

Too close to the sun for easy viewing at the beginning of the month, Mercury will gradually move into the morning sky during February and will reach its greatest western elongation on the 16th. The angular distance from the sun that Mercury achieves (26 degrees) will be the greatest for any of this year's western elongations. And yet this is an unfavorable time to see the planet after all; owing to the low angle of the ecliptic, Mercury will not be very far above the eastern horizon at sunrise. If you have an absolutely clear view of the eastern horizon, you might catch a fleeting glimpse of the +0.1 magnitude planet. With low angle, horizon haze and rising heat waves rendering telescopic observation useless, you're better off waiting till April when this innermost world will reach greatest eastern elongation, well placed for viewing in the western sky.

Venus

Venus remains the brightest object in the morning sky throughout the month; its magnitude is a brilliant -3.4. As its distance from Earth increases

PREDICTIONS FOR COMET WEST



Date	Mag.	R.A.	Dec.	Comet Sets	Sun Sets
Feb. 11	4.5	22^h48^m	-23°10'	5:30 p.m.	5:26 p.m.
Feb. 16	3.0	23^h03^m	-19°11'	5:45 p.m.	5:32 p.m.
Feb. 21	0.5	23^h11^m	-12°30'	6:00 p.m.	5:38 p.m.
				Rises	**Rises**
Feb. 26	0.0	22^h46^m	-03°00'	6:40 a.m.	6:42 a.m.
Mar. 2	1.6	22^h04^m	+04°05'	5:35 a.m.	6:33 a.m.
Mar. 7	2.8	21^h36^m	+07°23'	4:55 a.m.	6:25 a.m.
Mar. 12	4.6	21^h19^m	+09°22'	4:15 a.m.	6:17 a.m.
Mar. 18	5.7	21^h08^m	+10°34'	3:50 a.m.	6:08 a.m.
Mar. 23	6.3	21^h00^m	+11°35'	3:30 a.m.	5:58 a.m.

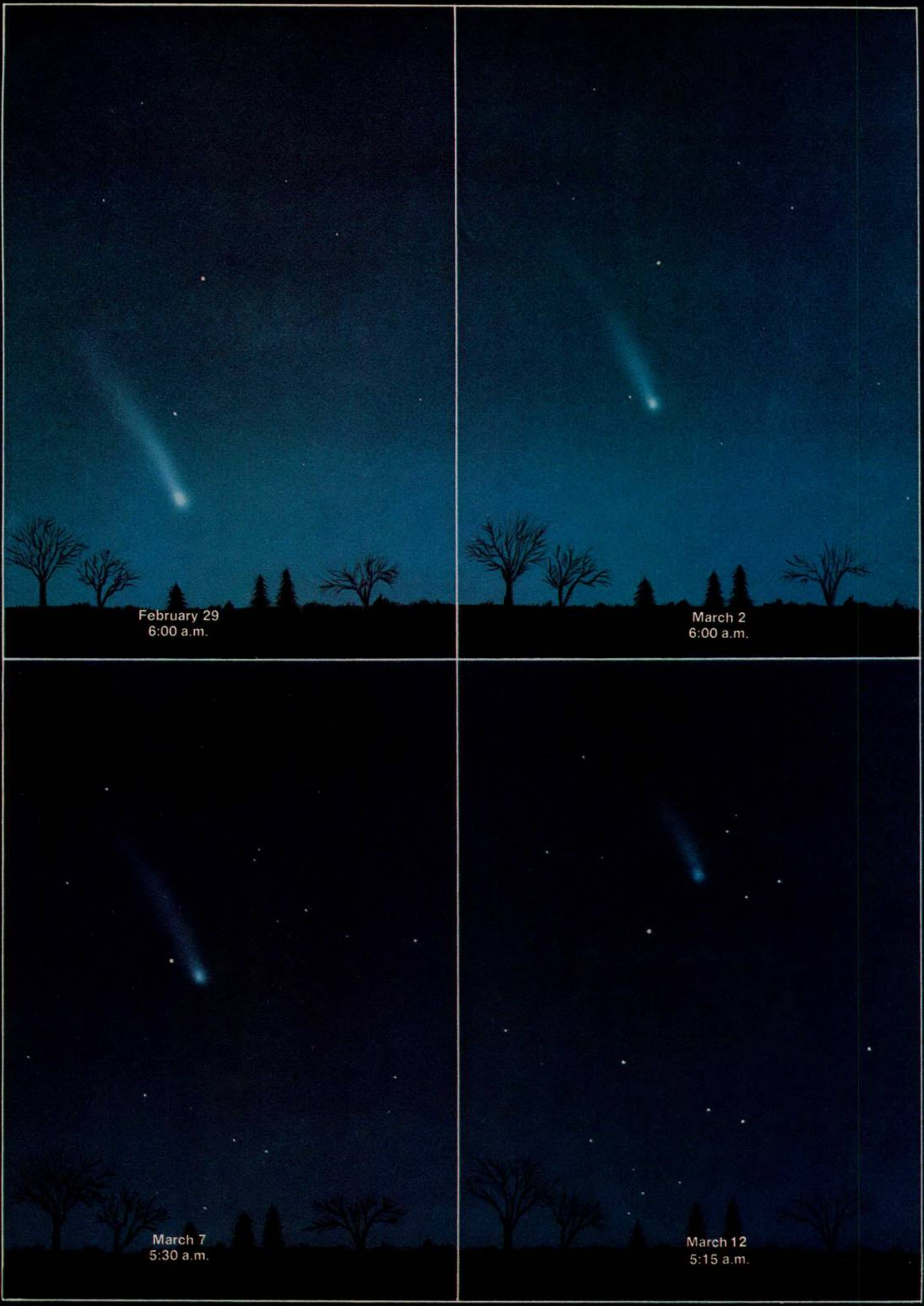
Magnitudes based on estimates by Brian G. Marsden of the Smithsonian Astrophysical Observatory. Sunset and sunrise time given for 42 degrees north latitude. Setting and rising times for comet West are approximate.

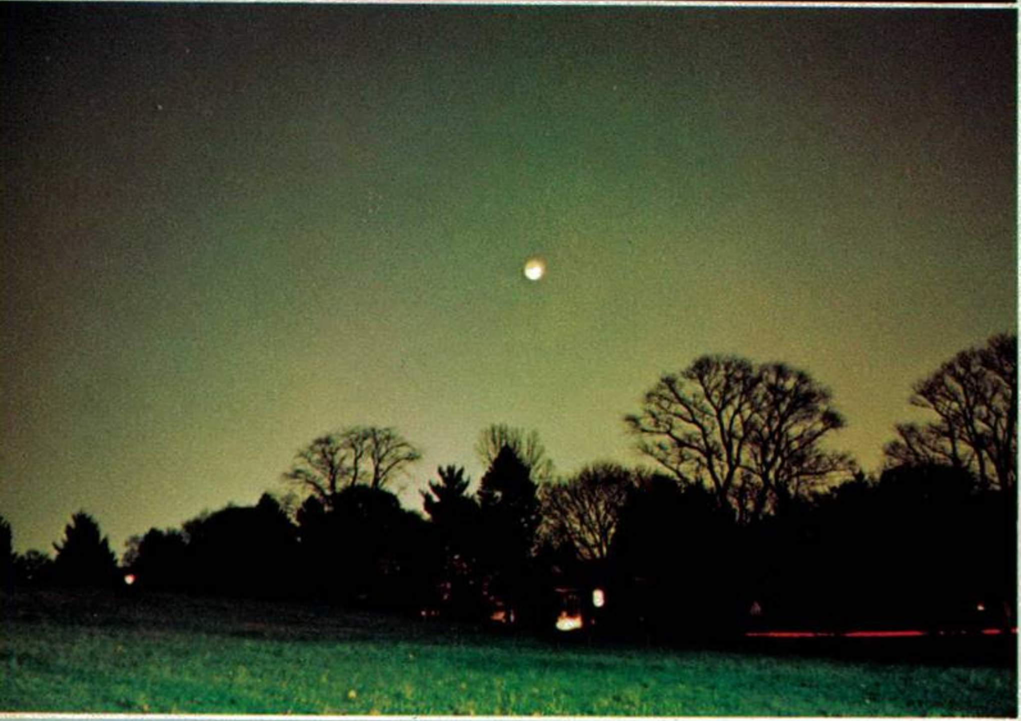
(from 119 to 133 million miles), so does the amount of its disk that is illuminated. Venus' "waxing gibbous" phase will move from 80 to 90 percent.

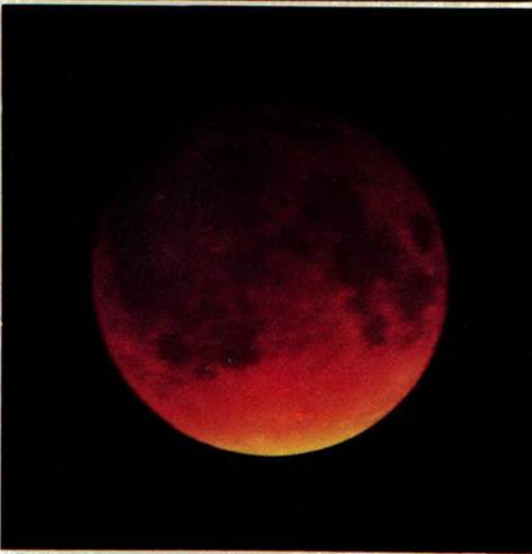
Mars

Now well past opposition, Mars has resumed its forward motion and is moving away from Earth again; its distance from us increases during February from 77 to 114 million miles. As it hurries away, its magnitude falls from -0.2 to +0.5. High in the sky at sunset, it is located between the horns of Taurus the bull. Mars is brighter than Aldebaran in the same

The map and table above show the path of comet West (and the sun) in February and March of this year. Perihelion (closest approach to the sun) will be reached on Feb. 25, after which the comet heads back out to space. The drawings on the opposite page demonstrate comet West's appearance in the morning sky just after perihelion. At upper left, comet West is a bright streak in the predawn twilight; its estimated magnitude at this time is about +1.0. Three days later (right), the comet has faded slightly but is farther above the eastern horizon at sunrise. As comet West recedes from the sun, it will be visible earlier in the morning in a darker sky, as shown at lower left; the star near the comet's head is second magnitude Enif (Epsilon Pegasi). By March 12 (right), comet West will have faded to fourth magnitude and will be dwindling rapidly in size. Map and artwork by Victor Costanzo.


February 29
6:00 a.m.
March 2
6:00 a.m.
March 7
5:30 a.m.
March 12
5:15 a.m.





constellation and is easily identified. You will notice a gradual decrease in the amount of surface detail visible through the telescope as the planet shrinks from 11.13 to 8.64 seconds of arc in diameter.

Jupiter

Jupiter is in Pisces, going down in the west at sunset; by the 28th, it sets at about 9 p.m. Its magnitude is now only -1.8 (as compared to -2.5 at opposition last October); it has no competition nearby and can be found easily. On Feb. 1, Jupiter is 488 million miles from Earth. It, too, is moving away from us, and its distance at month's end will be 522 million miles.

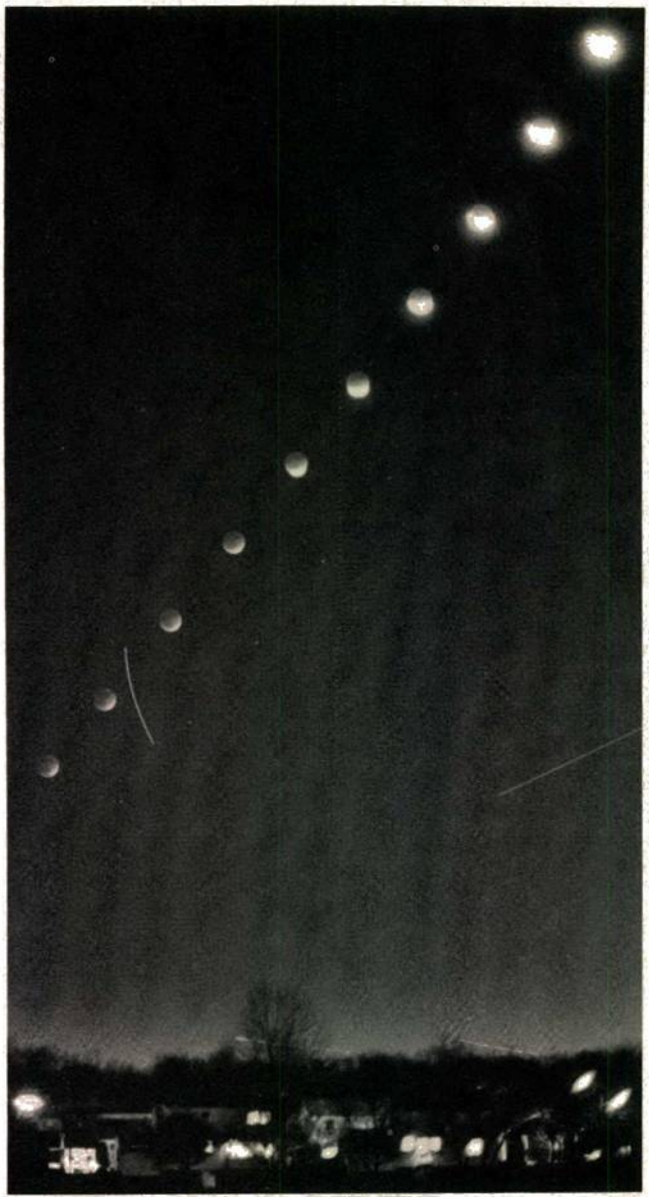
Saturn

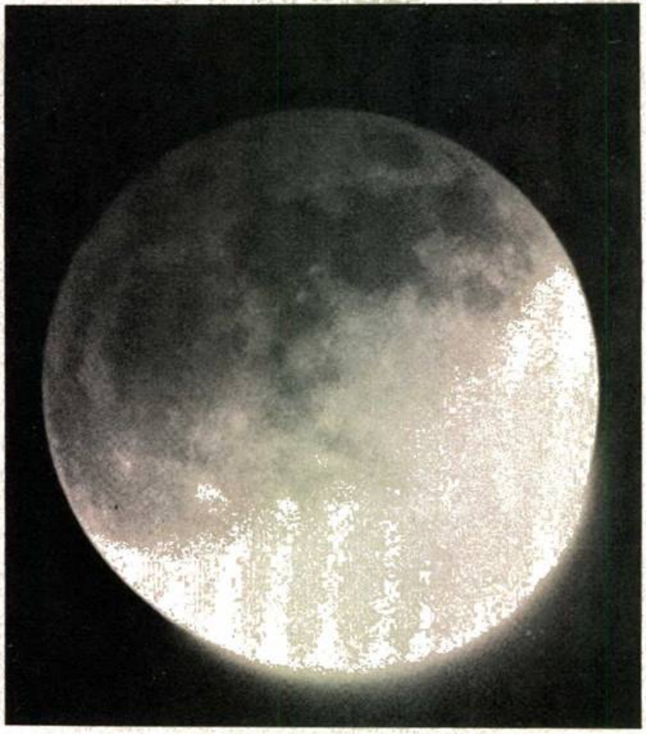
The ringed planet Saturn is just past opposition, still moving retrograde. Thus it heads back into Gemini from Cancer this month, but remains near these constellations' boundary line. It is high in the east at sundown and visible most of the night. Although it is receding from Earth, its distance does not change greatly and it shines at a steady magnitude 0.0 for most of February. Rhea, Saturn's second largest moon (magnitude 9.8), will be well placed for observation on the evenings of Feb. 8, 17 and 26, as it reaches its greatest elongation east of the planet. (See "Locating Saturn's Moons", page 36, January 1976.)

Uranus, Pluto

On the evening of the 10th, Uranus is stationary in the sky and begins its retrograde motion as it approaches opposition later this year. Located almost exactly on the Virgo-Libra border on the 10th, it moves farther back into Virgo during the rest of the month.

The dim, distant Pluto is also engaged in retrograde motion during February as it creeps toward a March opposition date. For those who are avid Pluto hunters, it can be found not far from the star Epsilon Virginis, which is high in the south at about 3 a.m.





The lunar eclipse of Nov. 18, 1975 produced a flurry of activity among photographers. The eclipse was nearing its end at moonrise over North America, and many pictures — including the seven second exposure at top left — were taken against a fairly light sky. The 20 second exposure below it produced an even brighter background. The moon's gradual emergence from Earth's shadow can be seen in the picture at lower left; the effect was produced by exposing the film for 100 minutes. Near the end of the eclipse, the moon was visible through clouds over Florida; exposure time was four seconds. An eight inch home built Newtonian was used for the 30 second exposure just below it; considerable detail on the shadowed surface is visible. A three inch Unitron refractor and yellow filter captured the moon for two minutes near totality. The photo at bottom right required two seconds through a Celestron 8. A one second exposure through an eight inch home built Newtonian yielded the picture at top right on this page, while 10 second exposures at 10 minute intervals brought the moon from totality to near eclipse end. Opposite: Left, top to bottom: Photographs by Bill Miles, Jeffrey Nutkowitz, Ralph Winrich. Opposite: Right, top to bottom: Photographs by Walt Zalph, James K. Rouse, Stanley H. Bonney, David Healy. Top right: Photograph by Bob Kimmel; Bottom right: Photograph by George F. Donnellan.

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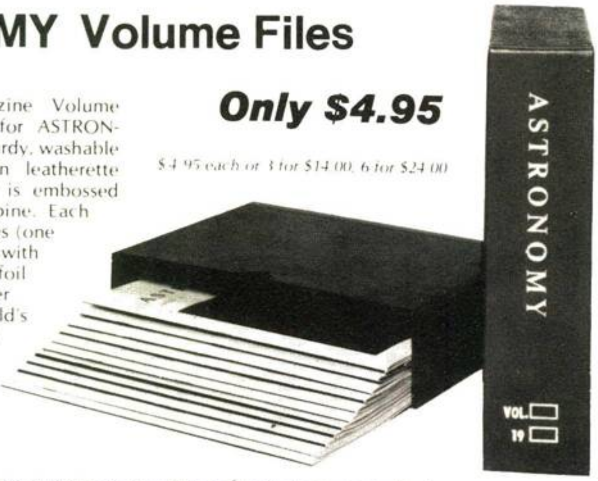

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ASTRO-MART

continued from page 50

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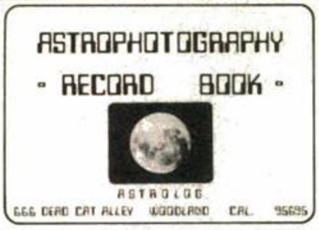

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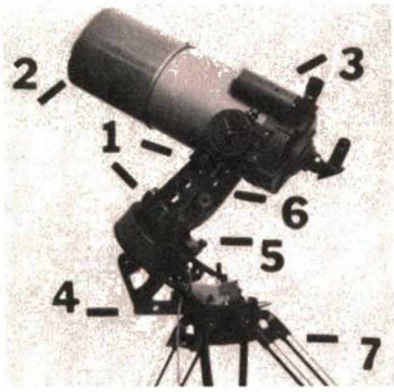

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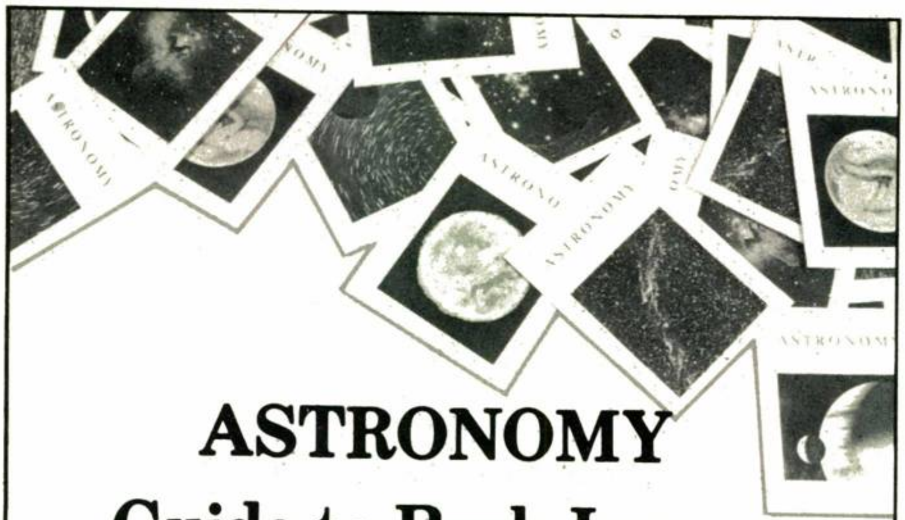

ASTRONOMY

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Reader interest in back issues of ASTRONOMY magazine is higher than ever. As a result, our stock of back issues is swiftly dwindling. Below is a guide to ASTRONOMY back issues that are still available. For your convenience it is updated monthly; issues not listed are depleted.

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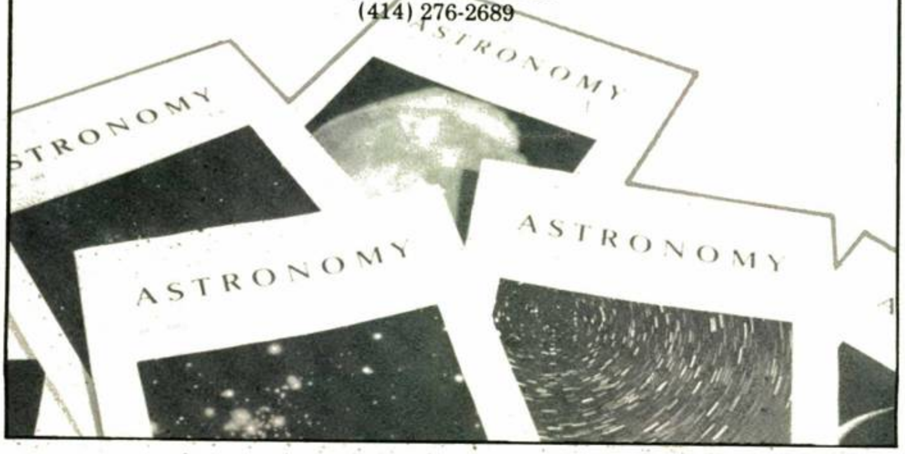

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ASTRO-NEWS

Latest News From the World of Astronomy

Pioneer 6 is 10 Years Old

On Dec. 16, 1975, NASA's Pioneer 6 had been circling the sun and returning good data for 10 years. This is believed to be the longest operating life ever attained by an interplanetary spacecraft.

Officials are delighted with this performance, especially because Pioneer 6 design specifications originally called for a minimum life span of only about six months.

Since launch in December 1965, the 140 pound Pioneer has, like a tiny planet, circled the sun almost 12 times, covering a distance of just over six billion miles. During its 10 year life, the spin-stabilized, solar-powered craft has radioed back measurements 24 hours a day from all sides of the sun.

Pioneer 6 made the first detailed measurements of the interplanetary medium. The workhorse spacecraft has measured the sun's corona, returned data on solar storms, and measured the tail of comet Kohoutek. It has made discoveries about the solar wind, solar cosmic rays, and the suns' magnetic field — all three of which extend beyond the orbit of Jupiter.

Pioneer 6 and its three sister spacecraft, Pioneers 7, 8 and 9 (also years beyond their designed six month lives), make up a network of solar weather stations, generally moving millions of miles apart from each other. All of the current Pioneers — 6 through 11 — were designed as rugged, relatively simple, low cost spacecraft, and all are still operating. They were built by TRW Systems and are managed by NASA's Ames Research Center, Mountain View, Calif.

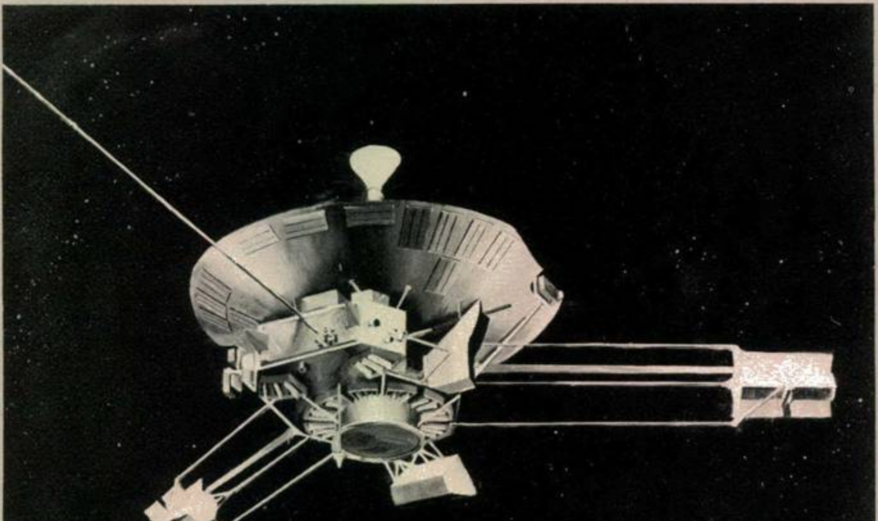
Pioneer 6 is drum shaped, about 35 inches high and 37 inches in diameter. Its sides are covered with solar energy cells, and divided by a narrow circular band with openings, from which four experiments and four orientation-and-timing sun sensors look out during the full-circle scans the spacecraft makes as it rotates.

Pioneer 6 has three antenna booms 120 degrees apart providing its own data handling, temperature control, communications and power system. It contains more than 56,000 parts.

Five of the six scientific instruments, and all other systems aboard Pioneer 6, continue to work well. The six instruments include: a magnetometer (of which a key part has worn out) to measure the sun's magnetic field; two instruments to study the million mile per hour solar wind of charged particles which constantly streams from the sun; a radio instrument to measure large scale segments of the solar wind between Earth and the spacecraft; two cosmic ray instruments that study the high energy particles that originate in the sun.

An experiment in celestial mechanics has used the spacecraft itself to measure the Earth-sun distance, planetary orbits, and relativity data. Since Pioneer has no energy inputs, but is powered by its solar cells and stabilized by its frictionless r.p.m. spin, it easily shows small gravity effects for these measurements.

Pioneer 6 helped to chart the solar wind and the twisting magnetic fields threading it, plus the streams of high energy particles that follow the fields out from the sun, All these phenomena co-rotate with the sun every 27 days. Masses of such data have allowed better understanding of the solar corona (from which the solar wind "boils off" into space), as well as the sun itself, for Pioneer has investigated particles of the sun that have been thrown off from its surface. When the spacecraft moves behind the sun (relative to



Pioneer 6, which recently marked its 10th year in space, is shown here in an artist's rendition. NASA artwork.

Pioneer 6 *continued on page 64*

New Gratings Triple Range Of 158" Scope

Two new gratings produced at the Kitt Peak National Observatory have effectively tripled the reach of the Mayall 158 inch telescope.

The gratings — thousands of closely spaced, fine parallel lines etched onto an aluminized glass surface — are of such high quality that Kitt Peak astronomers can now make detailed spectrographic studies of fainter stars than could previously be reached with the giant telescope.

Manufactured at Kitt Peak's own Gratings Lab, the new gratings are installed in the echelle spectrograph of the 158 inch telescope (second largest in the United States). The echelle spectrograph is mounted at the Cassegrain focus (just below the main mirror) of the instrument. According to project scientist Dr. Judith Cohen, this spectrograph is designed to obtain high resolution spectra of faint stellar and nebular objects.

For such studies astronomers use gratings, produced by a machine known as a ruling engine. Scribing up to 15,000 evenly spaced, uniformly deep lines or grooves per inch, such machines precisely rule an aluminum coating that is evaporated onto the surface of a mirror blank.

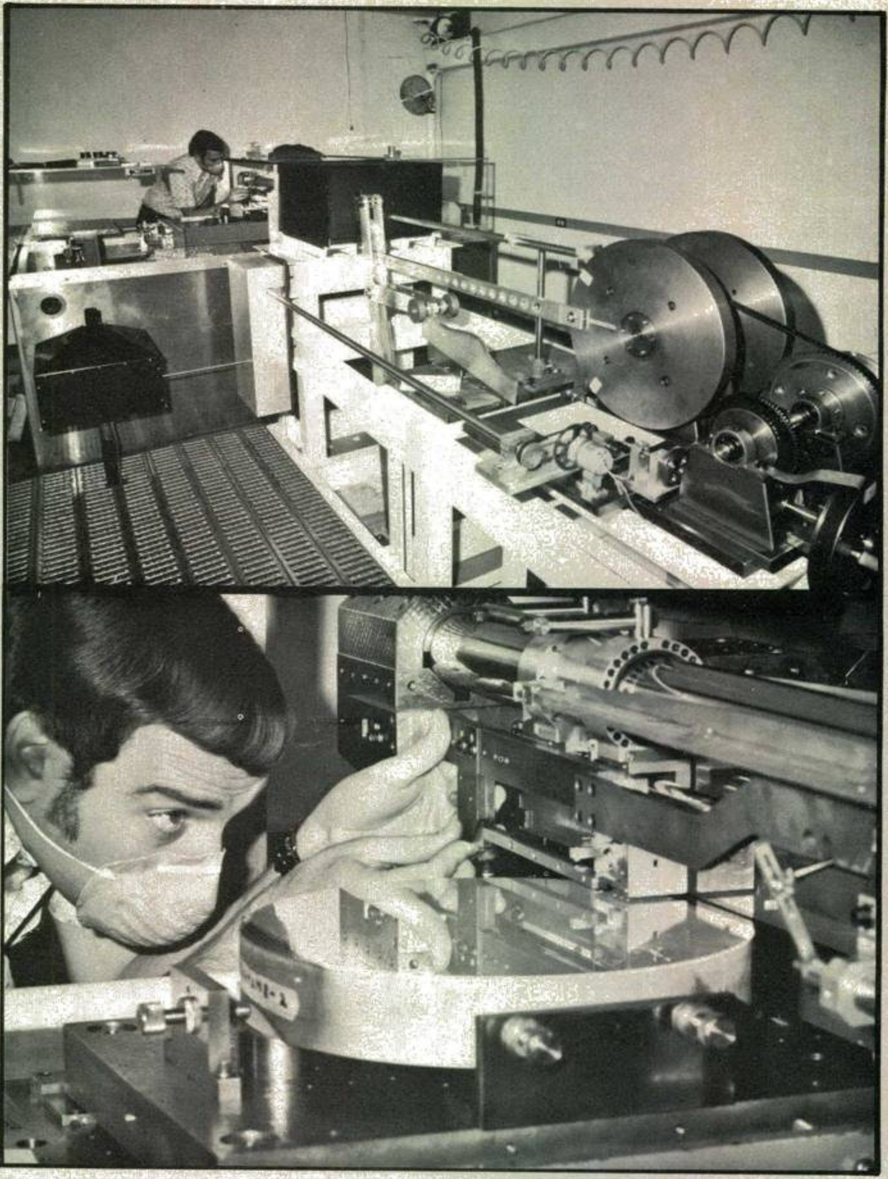
Kitt Peak's Harrison "C" ruling engine is the largest of its kind in the world, and the sole source of such large gratings in the U.S. Obtained in 1974 from the Massachusetts Institute of Technology, the engine is capable of ruling gratings up to 24 inches in width.

The larger the grating, the more precise and detailed the spectra — enabling scientists to obtain more complete data.

During production of an astronomical grating, the room housing the ruling engine is temperature-stabilized to within .01 of a degree, while the ruling engine itself is temperature-controlled to a range of plus or minus .004 of a degree.

The Harrison engine may work non-stop for weeks at a time to make a single grating. During manufacture, its diamond-tipped burnishing tool may travel over 70 miles on a 20 inch grating.

Future plans for the Kitt Peak Gratings Lab involve the production of large gratings for both Kitt Peak and other observatories.



The Harrison "C" ruling engine (above) at Kitt Peak is the sole source for large astronomical gratings in the United States. A technician (below) examines a fine adjustment on the machine. The circular grating on the engine is being scribed for astronomical use; the engine's diamond-tipped scribing tool may rule as many as 15,000 grooves per inch. Kitt Peak Observatory photographs.

Jovian Moons Given Permanent Names

After years of neglect, the outer moons of Jupiter have finally received official names. The eight tiny moons were the last members of any major planet's satellite system to remain nameless.

The names for moons VI through XIII respectively are Himalia, Elara, Pasiphae, Sinope, Lysithea, Carme, Ananke and Leda. Those names ending in the letter "e" belong to the moons that revolve about Jupiter in retrograde orbits. No name has yet been given to the recently discovered 14th moon.

Like the five previously named Jovian moons — Io, Europa, Ganymede, Callisto and Amalthea — all the newly assigned titles were taken from figures in classical mythology associated with Jupiter (or his Greek counterpart Zeus).

The new designations are not the same as those conceived by Brian Marsden at the Smithsonian Astrophysical Observatory which have been used unofficially. These latter names (Hestia, Hera, Poseidon, Hades, Demeter, Pan and Adrastea) may have been rejected from official consideration because many of them represent mythological figures whose Latin names have already been given to other objects in the solar system. Poseidon, for example, is the Greek name for Neptune, and Hades is the Greek name for Pluto.

Pioneer Aims for Saturn

Pioneer 11 successfully completed its most risky course-change maneuver on its historic trip to the ringed planet Saturn, according to NASA officials.

Controllers of the spacecraft increased its velocity by 67 m.p.h. to ensure that Pioneer can take one of the best options for a close flyby of Saturn: to pass between the rings and the planet itself, or to come in beneath the rings and continue upward outside of them.

The controllers had to cut off communication with Pioneer, which was 287 million miles from Earth, for several hours. During this time, the spacecraft followed previously given commands to change position, fire its thrusters, and then reposition itself to point its antenna back toward Earth and resume communications. This is the only maneuver during which contact with Pioneer was broken.

The main risk of the maneuver was that if problems had developed while Pioneer and its high-power, narrow-beam antenna were turned 25 degrees away from Earth, controllers would have had no information from the spacecraft about its status. They could have radioed commands to correct anything that had gone wrong, but would have had to guess the proper correction to make. (A series of such contingency commands had been prepared.) Though Pioneer 11 has proven very reliable, the operation of firing thrusters and making position maneuvers without communications could have caused difficulties.

There will be several more mid-course maneuvers over the next three years, all of which will be less difficult than the most recent one. Scientists will need to track the satellite for four months to determine the exact effects of the velocity change on Pioneer's trajectory to Saturn. But the probabilities are high that the target change was accurate.

Pioneer 11 will obtain the first close-up photographs of Saturn and its brightly lit rings when it reaches the planet in 1979. It flew past Jupiter in December 1974, photographing that planet's polar regions for the first time. Recent picture taking has shown that its electronic camera is still working well. Its current trip from Jupiter to Saturn spans 1.25 billion miles across the solar system.

During the Jupiter flyby, Pioneer traveled faster than any previous man made object (107,000 m.p.h.). Its current speed of about 40,000 m.p.h. is due to the boost in velocity it received from Jupiter's gravity and orbital motion, Because of this high speed, Pioneer 11 has already covered 1/3 the distance between Jupiter and Saturn — about 400 million miles.

If officials and scientists decide to aim Pioneer inside the rings, it should also get a close look at Titan, Saturn's sixth moon, en route. Titan, larger than the planet Mercury, is one of the best candidates in the solar system for harboring life.

1st Extragalactic Pulsar Discovered

Naval Research Laboratory scientists in Washington, D.C. have discovered the first pulsar outside the Milky Way galaxy. Located in the Small Magellanic Cloud at a distance of about 200,000 light-years, it produces x-ray pulses 84 times per minute with a force about a million times as strong as the sun.

The discovery was made with data obtained from an x-ray telescope used during the Apollo/Soyuz mission last July.

The pulsar, designated SMC-X1, is coupled to a blue giant star to form a binary pair — the members of which revolve about each other in a 3.89 day period. Gaseous matter is believed to flow from the giant to the tiny, rapidly spinning neutron star/pulsar. Because the neutron star may contain a mass equivalent to that of the sun compressed to a diameter of only ten miles, it possesses an enormous gravitational attraction near its surface and a magnetic field a trillion times as powerful as Earth's.

The wind of gas from the companion becomes a hurricane as the neutron star pulls matter through its magnetic and gravitational funnel down to its magnetic poles. The temperature of the infalling gas reaches a billion degrees as it piles up over an area of about a square mile at each pole. Intense x-rays, produced in the superhot gas surrounding the pulsar, flash out into space and past Earth like lighthouse beams.

Although two other pulsars have been found in binary systems located in the Milky Way, the newly discovered star in the Small Magellanic Cloud is the fastest and most powerful of the three.

NASA Launches Explorer

With the NASA launching of another satellite in its Explorer series, scientists are continuing close scrutinization of Earth's atmosphere. A major part of Explorer 55's duties will be to investigate the ozone layer in the equatorial region of Earth's atmosphere.

An ozone detector called a backscatter ultraviolet (BUV) spectrometer aboard Explorer 55, NASA's newest Atmosphere Explorer (AE) satellite, will provide information on the ozone layer in the area of the globe between latitudes 20 degrees north and 20 degrees south.

Immediately after the instrument was activated on Dec. 4, 1975, controllers at NASA's Goddard Space Flight Center in Greenbelt, Md. began receiving data on a checkout basis. The BUV spectrometer became fully operational within the month.

Six other instruments aboard the Explorer, which was launched Nov. 19, already had been activated, and five more were turned on after the BUV spectrometer went into operation.

The ozone detector was added to the satellite last spring by NASA as part of the agency's program to measure the atmospheric distribution of ozone on a global scale. The equatorial region is thought to be one of the most active regions of ozone production in the atmosphere.

The ozone layer is a planetary cover that shields Earth from most of the sun's dangerous ultraviolet radiation. Scientists have expressed concern that man made pollutants are building up in the atmosphere at such a rapid rate that they will begin depleting the ozone layer before 1980. A serious reduction in the ozone cover, and subsequent increase in the amount of ultraviolet light striking Earth, could lead to an increase in skin cancer, as well as changes in the average temperature of the atmosphere.

Information returned from the BUV spectrometer in conjunction with the other experiments aboard Explorer 55 may represent a major step in understanding the interaction of upper atmosphere components with ultraviolet light and the resulting impact on the ozone layer.

In addition to ozone information, instrumentation aboard the AE satellite is designed to return data on Earth's heat balance and energy conversion mechanisms, and on the flow of heat or energy from one hemisphere to the other.

Soviet Space Shots Point to Manned Interplanetary Flight

The flights of Soyuz-20 and Cosmos-782 late last year underline the USSR's strong interest in long-duration manned and unmanned space missions. They point up the seriousness of Moscow's announced intentions to make a manned interplanetary flight as soon as possible.

Soyuz-20 was the latest in a series of about 50 spacecraft of that type (unmanned test flights were called "Cosmos" or "Zond"). This Soyuz was sent into orbit without a crew to test an automatic system of resupplying Soviet Salyut space stations.

Two days after launch, Soyuz-20 docked automatically with the Salyut-4 space laboratory (which had been in orbit slightly less than a year). Soviet space officials described how future missions of this type would carry food, water, scientific equipment and oxygen to the marathon crews who are expected to spend three or four months in space on board Salyut-5 next year.

Though a biological hitchhike experiment was installed in the cabin of Soyuz-20, the main purpose of the flight was engineering development of more flexible ground-to-space supply systems. This goal was completely satisfied.

Coincidently with the flight of Soyuz-20, the Soviets launched the third in a series of biosatellites. Named Cosmos-782, it carried biological specimens for testing the effects of weightlessness and space radiation, and a new type of centrifuge for the artificial simulation of gravity.

The biological experiments weren't all from Russia. Other Eastern European countries, France and the United States also contributed. This was the first American experiment launched by the Soviets.

The satellite — actually a remodeled version of the old Vostok space cabin — circled Earth for three weeks before landing. While studying the Cosmos speciments, project scientists began planning for the next biosatellite mission, scheduled for early 1977.

These studies of space medicine, environmental control systems, and space resupply vehicles are all part of an explicit Soviet goal: the ability to keep cosmonauts in space for 18 months or more — long enough for a flyby mission to the planets.

Pulsars May Be Superfluid

The mysterious stars known as pulsars are probably fluid — or, more precisely, *superfluid.*

A superfluid is matter in an exotic state which flows without friction; once stirred into motion, a superfluid will swirl forever. Helium at a temperature near absolute zero is the only such matter known on Earth; it defies gravity by climbing over the rim of its container.

Columbia University astrophysicists have determined by x-ray studies that the surface temperature of the pulsar at the center of the Crab nebula is no more than nine million degrees Fahrenheit. Such a low temperature rules out any state of matter other than superfluidity in this spinning neutron star.

Theorists have predicted that if the Crab pulsar were not superfluid, its surface temperature would be 16 million degrees Fahrenheit; this temperature should be about 5.5 million degrees for a superfluid. Dr. Robert Novick of Columbia believes that the observed upper limit of the pulsar's temperature "falls so strikingly far below the 16 million degree figure that it excludes the possibility that the pulsar is not superfluid."

Most of our knowledge of pulsars is still theoretical, he said, "but this finding is strong and convincing evidence that at least this pulsar, and perhaps every one, is superfluid. If it is not, then the theories are wrong."

To make their measurements, the Columbia scientists designed special x-ray detection devices that were placed aboard rockets launched in November and December 1974. As a first step in their temperature-taking, they had to distinguish x-rays given off by the pulsar itself from those emitted by the entire nebula.

Scientists took advantage of an eclipse of the Crab nebula by the moon — an event which takes place about every 11 years and was the first since pulsars were discovered in 1967. At the moment the moon blocked the pulsar's rays, emissions from the rest of the nebula alone were recorded. When the eclipse ended and radiation from the pulsar was again part of the total data being received, the scientists could accurately separate and identify it. Pulses of x-rays burst from the rapidly spinning star 30 times per second.

Next, the scientists looked between these pulses for a different kind of x-ray — a continuous (nonpulsing) thermal x-ray. They found none — thus establishing the upper limit of the pulsar's surface temperature at nine million degrees. Thermal x-rays could be generated only at higher temperatures.

The findings do not establish a lower limit on the pulsar's temperature, but Novick believes that on the basis of current theory, there need not be one to prove superfluidity.

Pioneer 6 *continued from page 61*

Earth), studies of its radio signal added to our knowledge of the solar corona, through which the signal passes.

The four sun-orbiting Pioneers help predict solar storms when they are positioned behind the sun; they can record events on the solar surface up to two weeks before they become visible from Earth. Huge bursts of solar wind can buffet and vastly distort Earth's magnetic field for as long as a week. Such "geomagnetic storms" may trigger Earth's long-term weather patterns. Pioneer's instruments have also provided new understanding of Earth's magnetosphere. which shields us from high energy particle radiation.

The longevity of Pioneer 6 has allowed important studies of the solar wind by two spacecraft, one millions of miles "downwind" from the other. In November 1969, Pioneer 6 (inside Earth's orbit) and Pioneer 7 (outside it) were aligned on the same solar wind streams and magnetic field lines. A similar lineup occurred with Pioneer 8 in September 1970. In March 1974 the craft measured solar phenomena during a fortuitous three-spacecraft lineup. Pioneer 6, inside Earth's orbit, made a study of the solar wind, while the much younger Pioneers 10 and 11 measured the same stream about 10 days later almost a half billion miles away near Jupiter.

In September 1975, Pioneer 6 was able to team up with the new United States-German Helios satellite, which was six million miles inside the orbit of Mercury, closer to the sun than any spacecraft has yet gone — thus completing the total picture of data compiled from near the sun, very far away from it, and somewhere in between.

Because newer missions have required tracking time on the "big dish" antennas of NASA's Deep Space Network, Pioneer 6 has often been pushed aside. But it has continued transmitting information, and about half of the 50 billion bits of data it has sent have been received on Earth.

"Pioneer 6 is such a good spacecraft," comments Project Manager Charles F. Hall, "that we may get another 10 years out of it."

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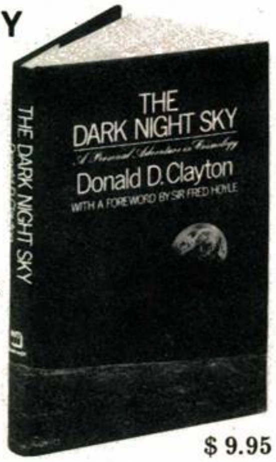
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FEBRUARY

by

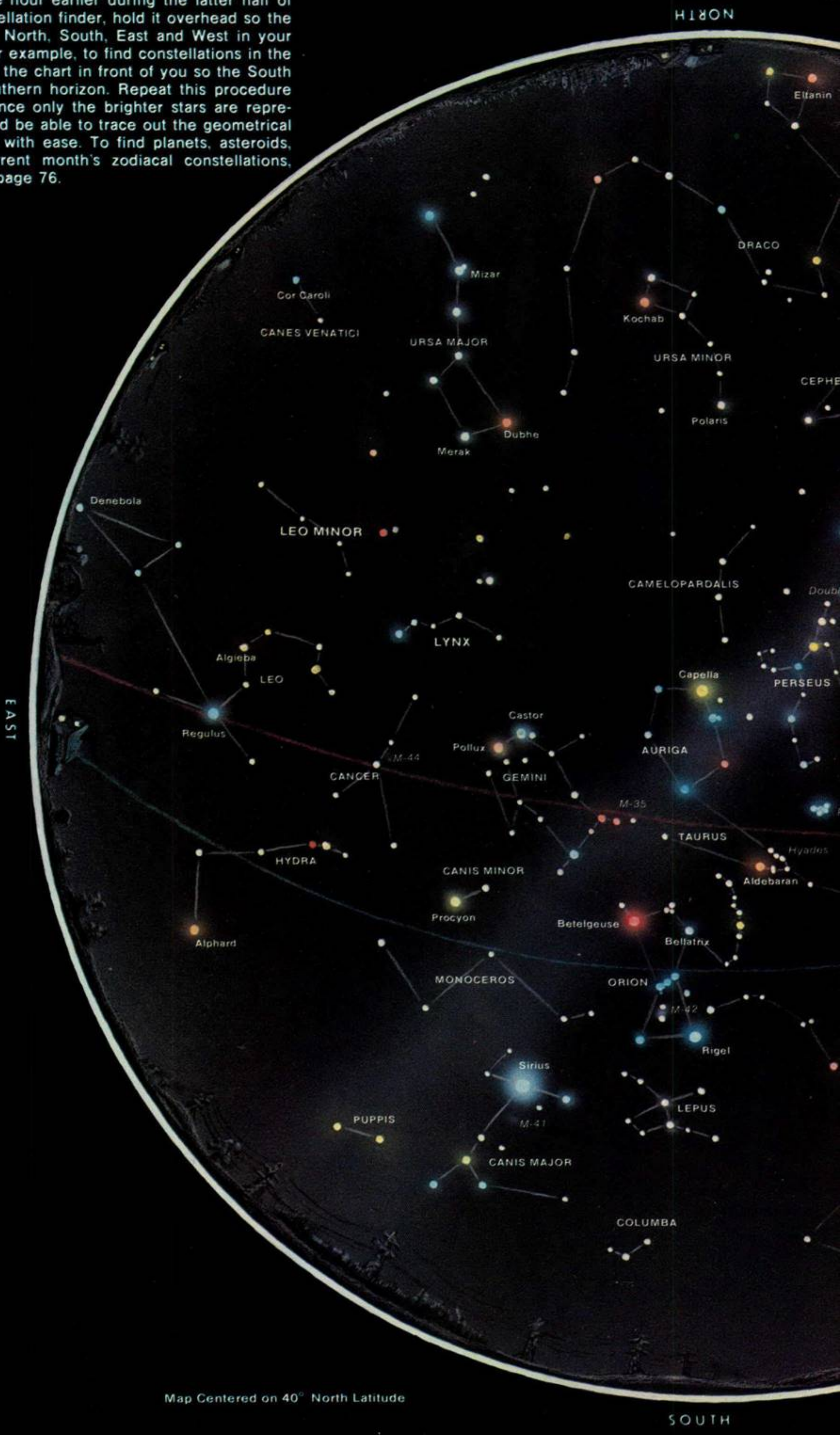
James Mullaney and Henry J. Phillips

Throughout the winter months, Orion the hunter dominates the sky as does no other constellation during any season. The dazzling brightness of all its major stars and its distinctive manlike pattern inevitably draw the attention of every stargazer, and other constellations take second place to this dominant figure. They cluster around Orion like people of the court surrounding a member of royalty, or (to use a more modern comparison) like fans around their favorite singer.

But these other star groups have attractions of their own; some of them contain brilliant stars, and it is only the overpowering presence of the hunter that seems to diminish their interest. Actually, almost all the winter constellations — if less bright than Orion — are quite as distinctive. The ancients recognized this, and the great majority of February's star patterns date unchanged from antiquity.

This month, the eastern side of the "great circle" of first magnitude stars reaches the zenith, and several of the constellations connected with them become more noticeable. Pollux is one of these stars; it and its companion Castor are the two "head lights" of Gemini the twins. According to Greek mythology, Castor and Pollux were the twin sons of Zeus and Leda; in one of his most flagrant at-

This Star Dome rendering approximates the sky as it appears at about 8 p.m. Local Standard Time early in the month. The same constellations are visible one hour earlier during the latter half of the month. To use this constellation finder, hold it overhead so the compass points line up with North, South, East and West in your backyard or viewing area. For example, to find constellations in the southern part of the sky hold the chart in front of you so the South compass point faces the southern horizon. Repeat this procedure for East, West and North. Since only the brighter stars are represented in this map, you should be able to trace out the geometrical shapes of the constellations with ease. To find planets, asteroids, etc., visible among the current month's zodiacal constellations, refer to the planet finder on page 76.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Capella
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HYDRA
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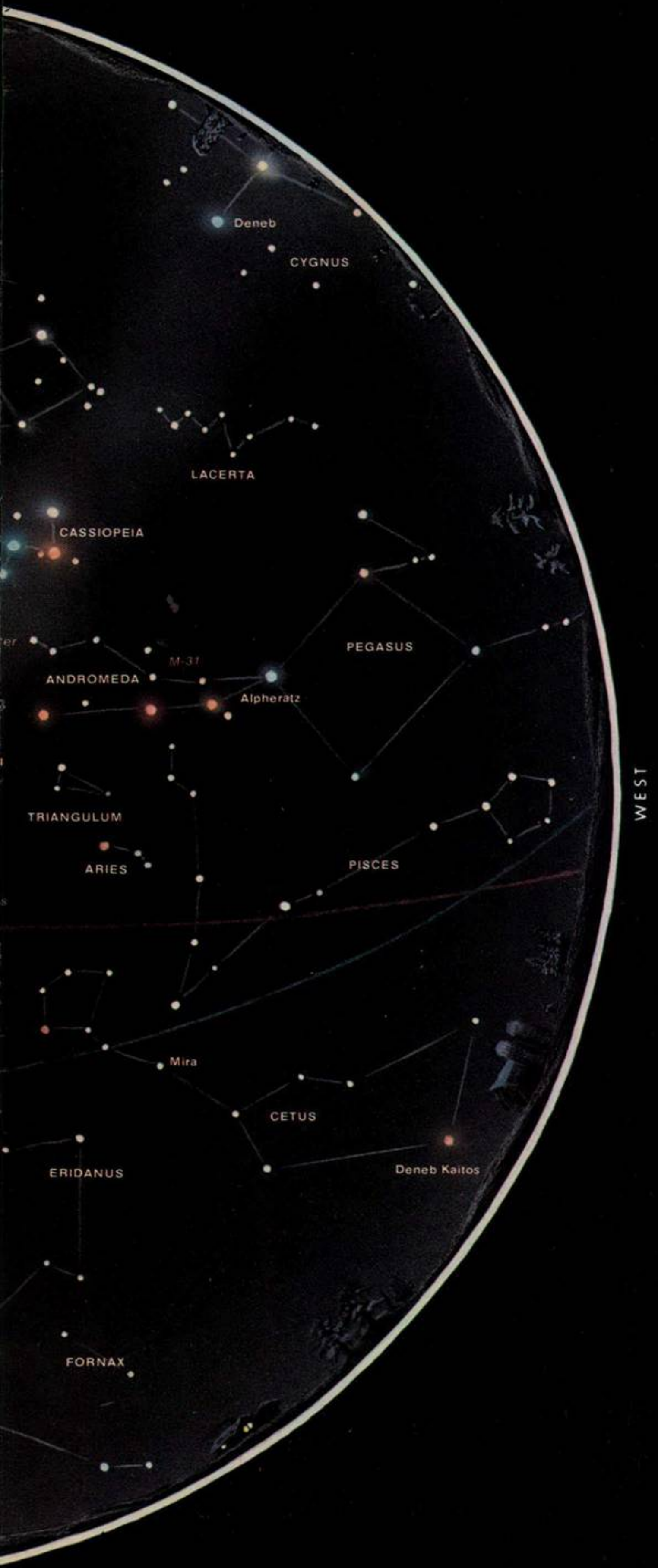


Map by Adolf Schaller

tempts to outwit his jealous wife Hera, Zeus changed himself into a swan before visiting Leda. The myth does not record whether or not Hera was fooled, but four children were born of the match — two of whom were mortal, and two divine. One of the immortal children was the famous Helen of Troy, and the other was Pollux. Castor was unlucky enough to be born mortal, as was the fourth child, Clytemnestra, who later achieved fame as a husband murderer.

Despite their different natures, the brothers were very close and shared several adventures, including the quest of the Golden Fleece aboard the ship Argo. Castor also became well-known as a horse trainer, while Pollux chose boxing as his profession. Eventually, when Castor died, his brother was so grief-stricken that he offered to renounce his own immortality if Castor could be restored to life. Instead they both were placed in the sky; the reason given for the unequal brightness of the two stars was that Pollux, being immortal, rated a brighter star than Castor.

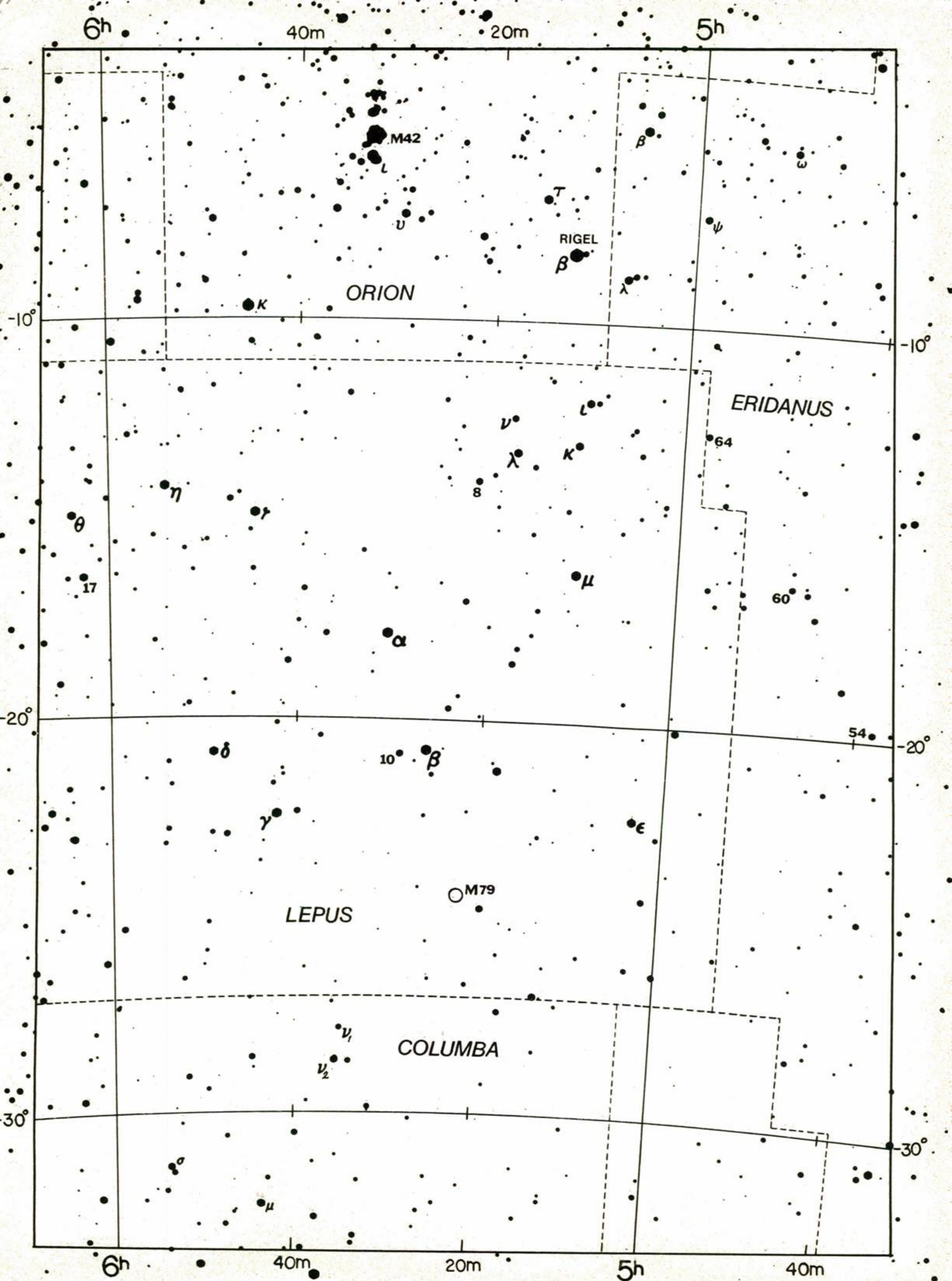
The two stars have almost universally been recognized as a sky couple — usually both male, but sometimes male and female. They have also been two peacocks, two sprouting plants, or two kid goats following Capella, the she-goat, across the sky. In the Chinese zodiac, however, there is just one figure here: an ape. A popular Chinese custom is to give each year a title based on the successive contellations of their zodiac; the next Chinese Year of the Ape will fall in 1981.

The rest of Gemini extends south and west toward Orion, and there are several fairly bright stars in the southern part of the constellation. The summer solstice (the point at which the sun is highest in the northern sky and summer begins) is located in Gemini, very close to the border of Taurus; it will move into that constellation before the end of this century.

Continuing along the great circle south of Gemini are the two dog stars, Procyon and Sirius. The name Procyon literally means "before the dog" — referring to the fact that it rises about 40 minutes before Sirius. Procyon lies in Canis Minor, the little dog, while Sirius is the brightest star of Canis Major, the big dog, as well as of the entire sky.

These two stars have been associated with Orion from earliest times, although originally it was Canis Major alone that represented a dog. To the Greeks, Procyon was an isolated star, belonging to no constellation but complete in itself. Even today, Canis Minor contains only one other star visible to the naked eye; it is also devoid of telescopic objects of interest. Procyon has the field to itself. No other first magnitude star so completely dominates its constellation (with the possible exception of Fomalhaut in Piscis Austrinus).

Canis Major, on the other hand, is a very rich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Photograph by John Sanford/Map by Victor Costanzo

constellation and would be one of the glories of our sky if it were farther north. There are many ancient references to the dog, generally as the companion of the giant figure nearby. But most modern experts are fairly certain that these are not references to the entire constellation, but to Sirius alone. It is inescapable that Sirius — as the brightest star — should have countless legends and myths connected with it. It is the only star that can be definitely identified in Egyptian records, for its rising at the summer solstice marked the beginning of the inundation of the land by the Nile River. This annual event led to worship of the star as the beneficial influence that brought about the flooding.

The name Sirius means "sparkling" or "scorching", and it was generally thought that the presence of both Sirius and the sun in the sky at the same time was the cause of hot weather — thus the origin of the term "dog days" for the hottest and most sultry summer days (something the average stargazer is not likely to remember when viewing Sirius in the winter sky).

It is only natural that the dog figure should eventually have come to form the entire constellation Canis Major, and it has never had any important mythological significance other than as Orion's dog.

Between the two dogs, and separating them from each other, is one of the few modern constellations found in the winter sky. Monoceros the unicorn was invented by Bartschius for his star catalog in the 17th century. It contains no stars brighter than fourth magnitude and, in fact, the Milky Way is fainter in Monoceros than in any other part of the sky. Like most modern constellations, its primary purpose seems to be to fill up unoccupied space between the classic figures.

Astronomers who introduced such figures as Monoceros were not interested in mythology, for the most part; as a result, the constellations they introduced are not nearly as picturesque as the old groups. Some of these modern constellations seem to have been invented on a mere whim. For example, the astronomer Hevelius once remarked that to distinguish anything in one area of the sky, a person would need the eyes of a lynx. Accordingly, he concocted the constellation Lynx and placed it in that area. It can be found in the northeast between Gemini and the Big Dipper. Hevelius' crack is certainly justified, for Lynx is notable for little but its emptiness.

Mercifully, most of these synthetic constellations have disappeared forever from our star charts, and there is no need to try and find such groups as the Typewriter (which one scientist placed just east of Sirius) or the Sceptre of Brandenburg (between Lepus and Eridanus). However, we still have Fornax the furnace — located in a bend of the river Eridanus and found just above the horizon in the southwest.

Another 17th century invention lies far to the south, just above the horizon in our latitudes. This is Columba the dove. When first formed, it was intended to represent the dove that brought the olive branch to Noah's Ark. This interpretation is still available to those who want to use it; others may prefer to see the dove of peace in this small group. Its stars are not very bright, and you may not be able to make it out through horizon haze.

As here on Earth, in the sky we also find the poor rabbit perpetually pursued by the hunter. The celestial counterparts of this familiar scene are Lepus the hare and, of course, Orion. On February evenings, Lepus can be found north of Columba, 1/3 of the way up the sky from the southern horizon and directly beneath the feet of the great hunter.

Overshadowed by the brilliant winter constellations (including Orion), the Lepus region seems largely neglected by observers both past and present. No doubt this star group's low altitude and the frigid nights of midwinter also contribute to this neglect. However, as Barns points out, Lepus "offers a feast of bounties with fair seeing".

Considerable uncertainty exists about the origins of this constellation. One account tells us that Lepus is a reduplication of the moon, and an astonishing amount of folklore connects the hare with this subject. This may have arisen from the many widely separated peoples who saw the figure of a hare in the maria of the moon (including the east Indians, Aztecs and Bantus). This association may have worked in the opposite direction, making Lepus into a sort of relative of the moon.

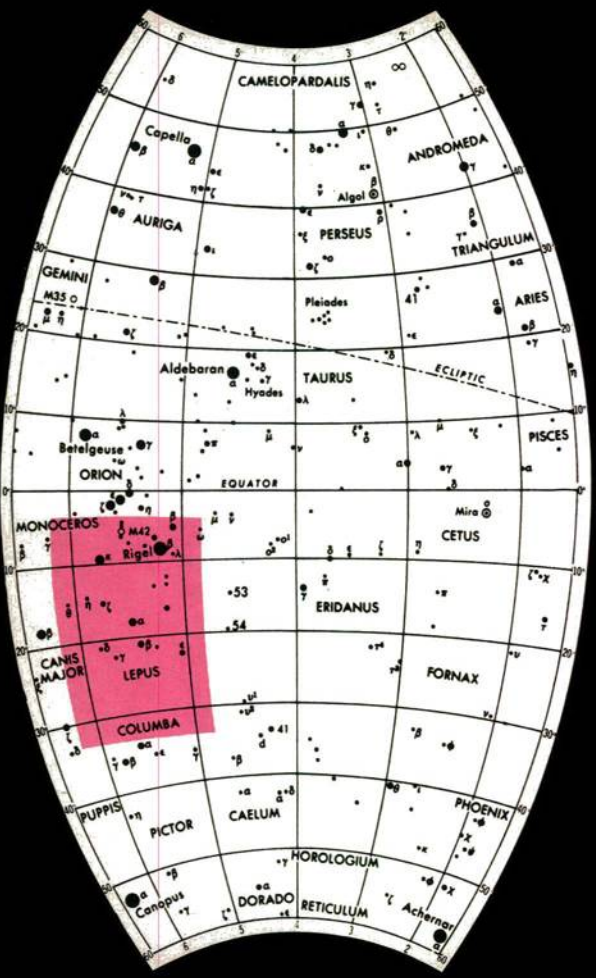
As Lepus sets in the southwest, Corvus the crow rises in the southeast — apparently contributing to the ancient belief that the hare detested the call of the raven.

Early Arabian stargazers regarded the four brightest stars of Lepus as camels drinking from the river marked by the adjoining constellation Eridanus. In fact, Nihal (the Arabic name of Beta Leporis) comes from the name of this particular configuration, while Arneb (Alpha Leporis) simply means "hare". Yet another account relates that the Egyptians recognized Lepus as the boat of Osiris, the great god of that country who was identified with Orion.

Perhaps the most appealing legend — at least to hunters — is simply that the hare was a creature that Orion especially enjoyed hunting; for this reason it was placed near him in the sky upon his tragic death.

One final note of interest concerning the hare: Clouds and low-lying horizon haze at times completely obscure the bottom portion of this constellation. On such occasions, only the ears and nose of the figure remain visible, and Lepus looks like some curious cosmic rabbit surveying the heavens about him from his celestial hutch!

Close-Up on the Lepus Region



Map from **Guideposts to the Stars**; reprinted permission of MacMillan Publishing Co., ©1972 by Leslie C. Peltier.

Stars in each constellation are indicated, in order of brightness, with the Greek Alphabet.

α	**Alpha**	η	**Eta**	ν	**Nu**	τ	**Tau**
β	**Beta**	θ	**Theta**	ξ	**Xi**	υ	**Upsilon**
γ	**Gamma**	ι	**Iota**	ο	**Omicron**	φ	**Phi**
δ	**Delta**	κ	**Kappa**	π	**Pi**	χ	**Chi**
ϵ	**Epsilon**	λ	**Lambda**	ρ	**Rho**	ψ	**Psi**
ζ	**Zeta**	μ	**Mu**	σ	**Sigma**	ω	**Omega**

Table of Objects — Lepus Region

Object	Type	Mag.	Size/Sep.	R.A.(1950)	Dec.
R	V:433^d	5.9-10.5	—	4^{h}57^m	-14°53'
κ Kappa	★2	4.5/7.5	3"	5^{h}11^m	-13°00'
* M-79	GC	8.4	3'	5^{h}22^m	-24°34'
α Alpha	★2	2.7/10.5	35"	5^{h}31^m	-17°51'
* H-3780	★4	7/8/9/8.5	76",90", 127"	5^{h}36^m	-17°30'
*γ Gamma	★2	3.8/6.4	95"	5^{h}42^m	-22°28'

*Detailed description in Eyepiece Impressions

OC	Open Cluster	PN	Planetary Nebula
GC	Globular Cluster	El	Elliptical Galaxy
EN	Emission Nebula	Sp	Spiral Galaxy
RN	Reflection Nebula	Ir	Irregular Galaxy

*2,3,4 Double/Multiple Star
V:#dhms Variable Star, Period days, hours, minutes
Nr Nova Star, recurring

Mag. Magnitude Sep. Separation

Even with the unaided eye, Lepus is of considerable interest to the stargazer, for it looks strikingly like its namesake. Four third and fourth magnitude stars [Alpha (α), Beta (β), Gamma (γ) and Delta (δ)] form an irregular and conspicuous quadrilateral in the sky. A curved line of three fourth and fifth magnitude stars [Zeta (ζ), Eta (η) and Theta (θ)] mark the back of the creature, while two of third magnitude denote the nose and forepaws [Mu (μ) and Epsilon (ϵ), respectively]. Finally, the ears are represented by a group of fourth and fifth magnitude stars [Lambda (λ), Iota (ι), Kappa (κ) and Nu (ν)] just south of Rigel in Orion.

Binocular observers will find much scope for exploration among the distant suns of Lepus. The frequent poor seeing of winter combined with this group's low altitude in our skies often causes a noticeable flickering of its stars, much like a group of out-of-season fireflies in the night.

Slow sweeping back and forth across the constellation on dark transparent nights reveals many star-rich fields, especially in the vicinity of Alpha. Dropping south on a line from Alpha to Beta, we find a solitary fifth magnitude star, just northeast of which 10 x 50mm or 20 x 60mm binoculars will reveal a tiny patch of light. This is the remote globular cluster M-79 — the only object of its class readily visible in winter.

Double star enthusiasts will find a number of pairs and triplets visible in 7 x 50 or 20 x 50mm binoculars in this region. For example, steadily held instruments will resolve Gamma into fourth and sixth magnitude components, 95 seconds of arc apart. Viewing this pair's fine color contrast does, however, require a telescope as discussed in Eyepiece Impressions below.

Another quest for binocular users is the remarkable variable star, R Leporis. A line from Alpha to Mu extended about four degrees to the northwest points directly at its location. When at maximum light near sixth magnitude, R can be glimpsed with the unaided eye on a dark night and is obvious in even the smallest of binoculars.

This restless supergiant sun waxes and wanes over a period of 433 days, becoming as faint as 10.5 magnitude. At such times it is invisible even in large aperture binoculars. Presently, R is hovering near the limit of 7 x 50mm glasses.

This star is a member of the class known as *long-period variables*. Such stars are invariably red supergiants of spectral class M, and their brightness can vary wildly over a period of time from very low to very high magnitudes. This change in brightness

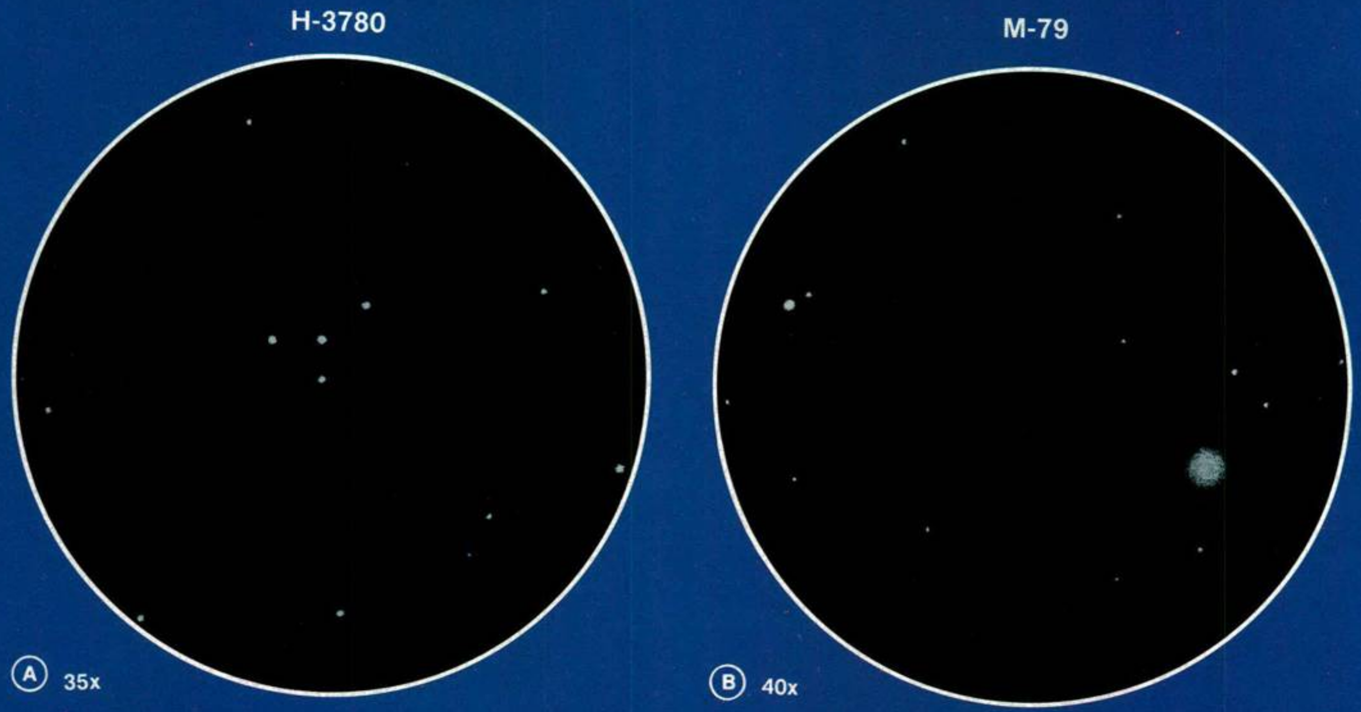


Diagram A represents the multiple star system H-3780, a group of four stars in a distinctive arrangement. A 2.4 inch Unitron refractor at 35 power is used to show the components in the center of a one degree field. Two of this system's members are very close binaries. In diagram B, a 3.5 inch Questar Maksutov at 40 power shows the globular cluster M-79 at one edge of the one degree field, not far from the triple star 41 Leporis. Larger apertures are necessary to resolve the outer haze of the cluster into stars, and even 12 inch instruments will not resolve the very dense core. Diagram C shows the nearby double star Gamma Leporis in the center of a one degree field. Smaller apertures than that used here — a four inch Edmund reflector at 40 power — will not bring out the delicate tints of the two stars. Although most observers see the fainter star as blue or purple, its color has also been given as garnet or green. Drawings by James Mullaney.

is thought to be the result of the star's pulsation: As the star contracts, it grows hotter and brighter, and then dims down again as it expands. The prototype of this kind of star is Mira [Omicron (*o*) Ceti], which is low in the southwest in February. Another example is Betelgeuse which has an irregular period of about 5-1/2 years — although Betelgeuse does not vary as widely in magnitude. Yet another example can be found in Lepus itself: The star T Leporis, located near Epsilon, ranges in magnitude from 7.4 to 13.5. At its brightest it is visible in binoculars.

R Leporis' chief attraction to visual observers is not its variability, but its vivid red hue. Well-known as Hind's Crimson star, it was described by him as "of the most intense crimson, resembling a blood drop on the background of the sky; as regards depth of color, no other star visible in these latitudes could be compared with it."

Eyepiece Impressions
H-3780

One of many overlooked surprises of the heavens is the unusual multiple star designated Herschel 3780. Readily found by sweeping six minutes due east of third magnitude Alpha Leporis with a low power eyepiece, this object often summons exclamations of delight at its sight — so unexpected is its appearance! Despite this, little attention has been paid it by today's astronomy enthusiast.

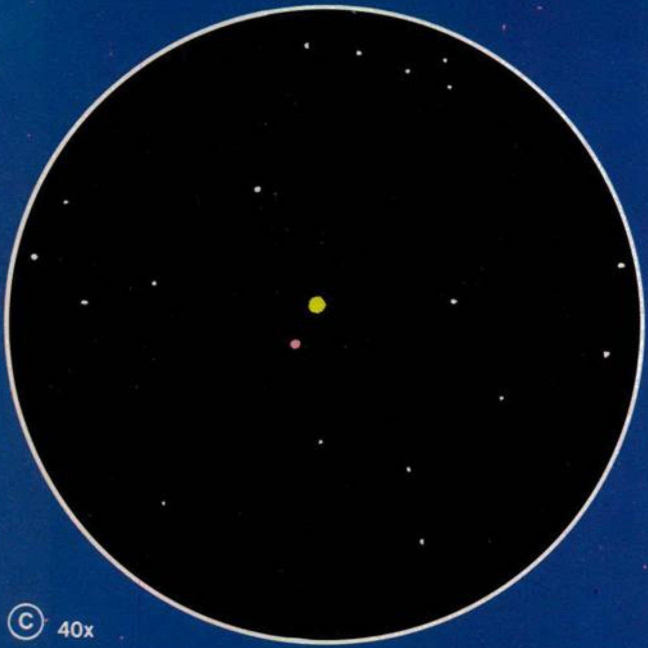
Small telescopes disclose a group of four stars strikingly arranged as shown in our drawing. A three inch reflector at 30 power gives a fine view of the scene. Published magnitudes of the individual stars are 7, 8, 8.5 and 9, but visually they seem much more nearly matched than these figures suggest. Perhaps the brightest member has faded, or the faintest star brightened? Taking the seventh magnitude component as the center of the group, the companions lie at distances of 76, 127 and 90 seconds, respectively.

At least one observer of the past referred to H-3780 as a "beautiful cluster for small telescopes" rather than a multiple star. Indeed, it is often difficult to distinguish between the two classes of objects with systems like this, and the Trapezium in Orion; there may well exist a continuous sequence from double to multiple stars to open clusters.

The classification "cluster" for H-3780 becomes even more appropriate when we consider that at least two of the members seen in small instruments are also very close binaries. The seventh magnitude component has been resolved into a 6.8 and 8.3 magnitude pair 0.7 seconds apart, while the ninth magnitude star is a 9.3 and 10.0 double of 1.3 seconds separation. Both close pairs require large amateur instruments to be seen, and offer a real challenge to 8 and 10 inch reflectors even in steady air.

M-79

Like some lost celestial sheep, the eighth magni-



Gamma Leporis

Ⓒ 40x

tude globular star cluster M-79 roams the winter sky of Lepus, far from the great flock of these objects that populate the summer heavens. One reason for its isolated position is the viewpoint from which we see it. Most globular clusters are arranged in a sphere around the center of our galaxy. In the winter we are facing away from the center when we look at the Milky Way, and globular clusters are rare.

Careful sweeping on dark nights reveals M-79 as a globe of light closely following the fifth magnitude triple star 41 Leporis (designated H-3752; components of magnitudes 5.4, 6.7 and 9.0; separations 3 and 59 seconds). As our sketch shows, both 41 and M-79 fit neatly in the same low power field — the latter flanked by a pair of faint stars.

Webb describes this object in his 3.7 inch refractor as "tolerably bright with my 64 (power), blazing in center; high power showed it mottled." Herschel saw M-79 as a beautiful cluster of stars in his large reflectors. Strangely, Barns does not even mention this out-of-place object despite a 10 inch reflector in clear California skies.

Webb's comment that Lepus is "so near the horizon that it can only be well seen on the meridian and opportunities must not be thrown away" applies especially to M-79. It is situated nearly 25 degrees below the celestial equator — rather low in the sky for most northern observers — and is best seen when transiting the meridian.

A three or four inch telescope at about 45 power in good seeing (image steadiness) shows a three minute diameter ball of light, with bright core and faint outer haze. This haze looks granular in moments of steady air and breaks into clumps of individual stars in six and eight inch instruments at medium magnifications. However, even a 12 inch reflector will not resolve the dense core of this remote stellar beehive for most observers.

Those using small apertures should watch for a curious aspect displayed by this cluster on nights of poor seeing — a trembling disk of light rapidly changing size and shape with fluctuations of atmospheric stability.

Gamma (γ) Leporis

One of the real telescopic attractions of Lepus is the fourth magnitude star Gamma, located in the body of the hare. Even a 2.4 inch (60mm) refractor at 35 power will readily resolve this object into a 3.8 and 6.4 magnitude duo some 95 seconds of arc apart.

However, at least a four inch telescope is needed to appreciate this pair's lovely hues. With insufficient light grasp, the two stars appear simply white or gray — their unsuspected beauty lying below the color threshold of the eye.

Smyth long ago described Gamma as light yellow and pale green in his six inch refractor (he was prone to seeing green among the companions of many pairs). With his 3.7 inch refractor, Webb gave the colors pale yellow and garnet — as did Olcott using a similar instrument. What hues does your telescope reveal in Gamma?

To observe the delicate tints of celestial gems like Gamma, well-corrected oculars such as orthoscopic or achromatic Kellners should be employed to avoid the introduction of spurious color. The object should also be placed at the center of the field of view and observed when on or near the meridian (at its highest in the sky) for best results.

As we have mentioned before in Star Dome, a slight defocusing of the image (outside rather than inside of focus) often enhances color contrast by spreading the star's light over a greater area of the retina. Interestingly, poor seeing often does this automatically for the observer — especially for pairs like Gamma at low declinations.

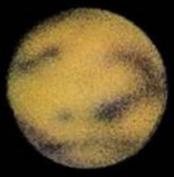
While the tints of many bright doubles such as Albireo [Beta (β) Cygni] and Gamma (γ) Andromedae are actually less striking in large than in small apertures due to excessive light overpowering the sensitive retina, Gamma Leporis becomes more attractive with increased telescopic size. As is often the case, Gamma's hues seem most intense and definite upon first looking into the eyepiece, and become less so with continued scrutiny.

One more notable fact about Gamma Leporis is that it is rather near the sun — only about 27 light-years away. Its apparent magnitude is lower than its absolute magnitude; it is thus one of those rare stars that appear brighter than they actually are. It has high proper motion and is rapidly changing its place in the sky. Considering how close it is, it might seem odd that Gamma's colors are so elusive. One almost wonders how near a star has to get before such things become noticeable!

Planet Finder

Ⓒ Ceres

Feb.	1	15
R.A.	$3^{h}57^{m}$	$4^{h}05^{m}$
Dec.	+20°51'	+21°51'
Mag.	+7.1	+7.3



Ⓐ Mercury

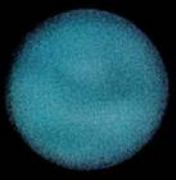
Feb.	1
R.A.	$19^{h}39^{m}$
Dec.	-18°25'
Mag.	+0.9

Ⓑ Mercury

Feb.	15
R.A.	$20^{h}09^{m}$
Dec.	-19°42'
Mag.	+0.2

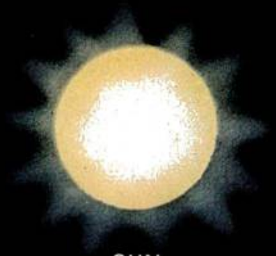
Ⓜ Mars

Feb.	1	15
R.A.	$4^{h}56^{m}$	$5^{h}04^{m}$
Dec.	+25°37'	+25°42'
mag.	-0.2	+0.1



Ⓝ Neptune

Feb.	15
R.A.	$16^{h}50^{m}$
Dec.	-20°57'
Mag.	+7.7

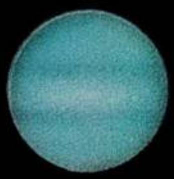


SUN

The sun is within the stippled zone throughout the month. Planets and stars near this area are not easily seen.

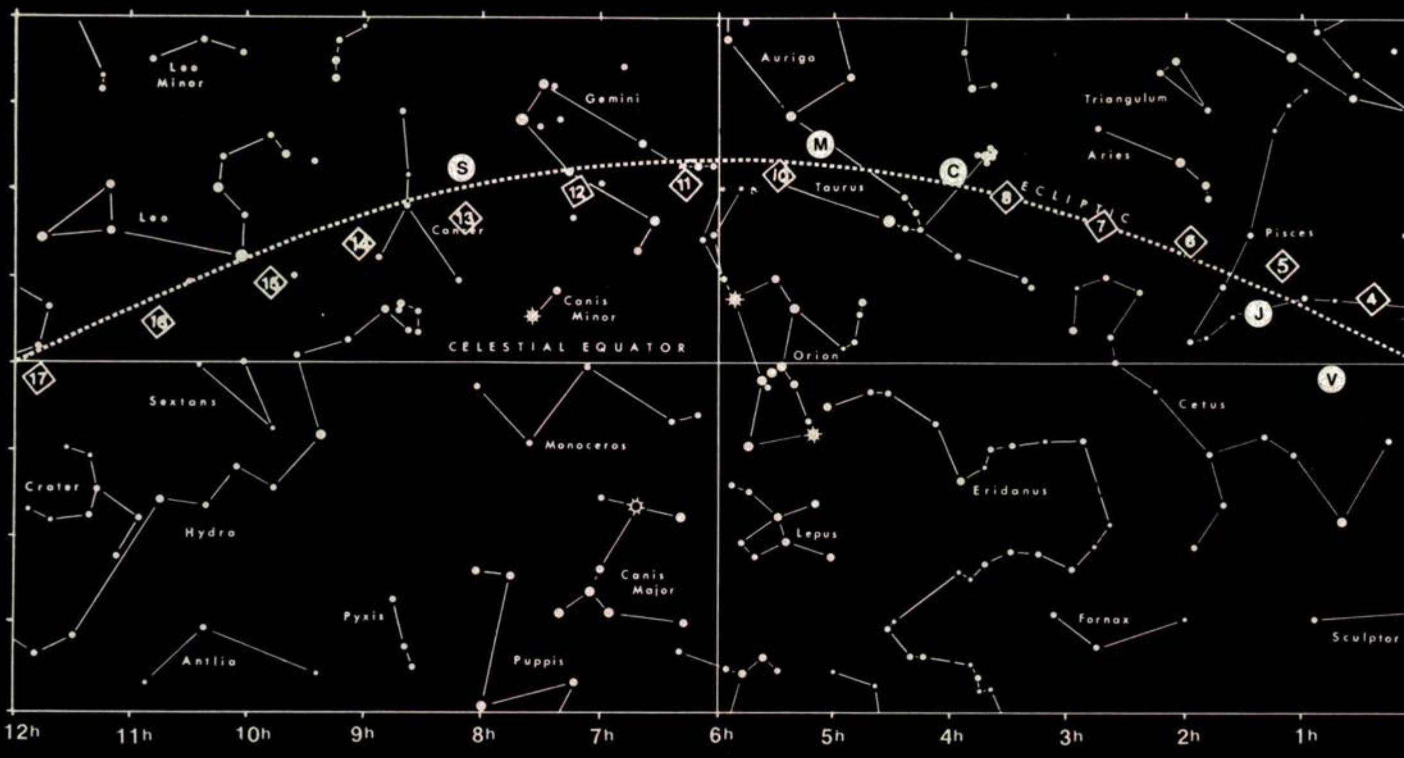
Ⓢ Saturn

Feb.	1	15
R.A.	$8^{h}02^{m}$	$7^{h}58^{m}$
Dec.	+20°46'	+21°00'
Mag.	-0.1	0.0



Ⓤ Uranus

Feb.	15
R.A.	$14^{h}20^{m}$
Dec.	-13°25'
Mag.	+5.7


Leo Minor
Gemini
Auriga
Triangulum
Aries
Leo
Cancer
Taurus
ECLIPTIC
Pisces
Canis Minor
CELESTIAL EQUATOR
Orion
Cetus
Sextans
Monoceros
Eridanus
Crater
Lepus
Hydra
Canis Major
Fornax
Pyxis
Sculptor
Antlia
Puppis
S
M
C
J
V
4
5
6
7
8
10
11
12
13
14
15
16
17
12h
11h
10h
9h
8h
7h
6h
5h
4h
3h
2h
1h

The chart shows the positions of the moon, planets and brightest asteroids for the current month. Letters within the circles correspond to the letters beside each object in the data section above the map. Additional information about each object is given there. R.A. = right ascension and Dec . = declination, the two coordinates used to locate astronomical objects. The general coordinate system is indicated around the edge of the map. Mag . = magnitude, a

February 1976

Ⓥ Vesta

Feb.	1	15
R.A.	0h45m	1h04m
Dec.	-1°40'	+0°50'
Mag.	+7.7	+7.9

Ⓙ Jupiter

Feb.	1	15
R.A.	1h13m	1h22m
Dec.	+6°24'	+7°25'
Mag.	-1.9	-1.8

Ⓨ Venus

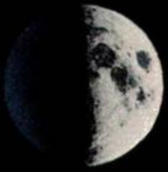
Feb.	1
R.A.	18h35m
Dec.	-22°17'
Mag.	-3.5

Ⓩ Venus

Feb.	15
R.A.	19h50m
Dec.	-20m53'
Mag.	-3.4

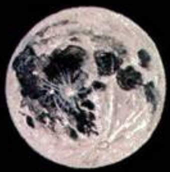
Ⓟ Pluto

Feb.	15
R.A.	13h08m
Dec.	+11°32'
Mag.	+14



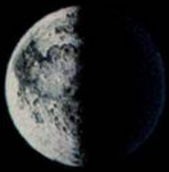
First Quarter

Feb. 8



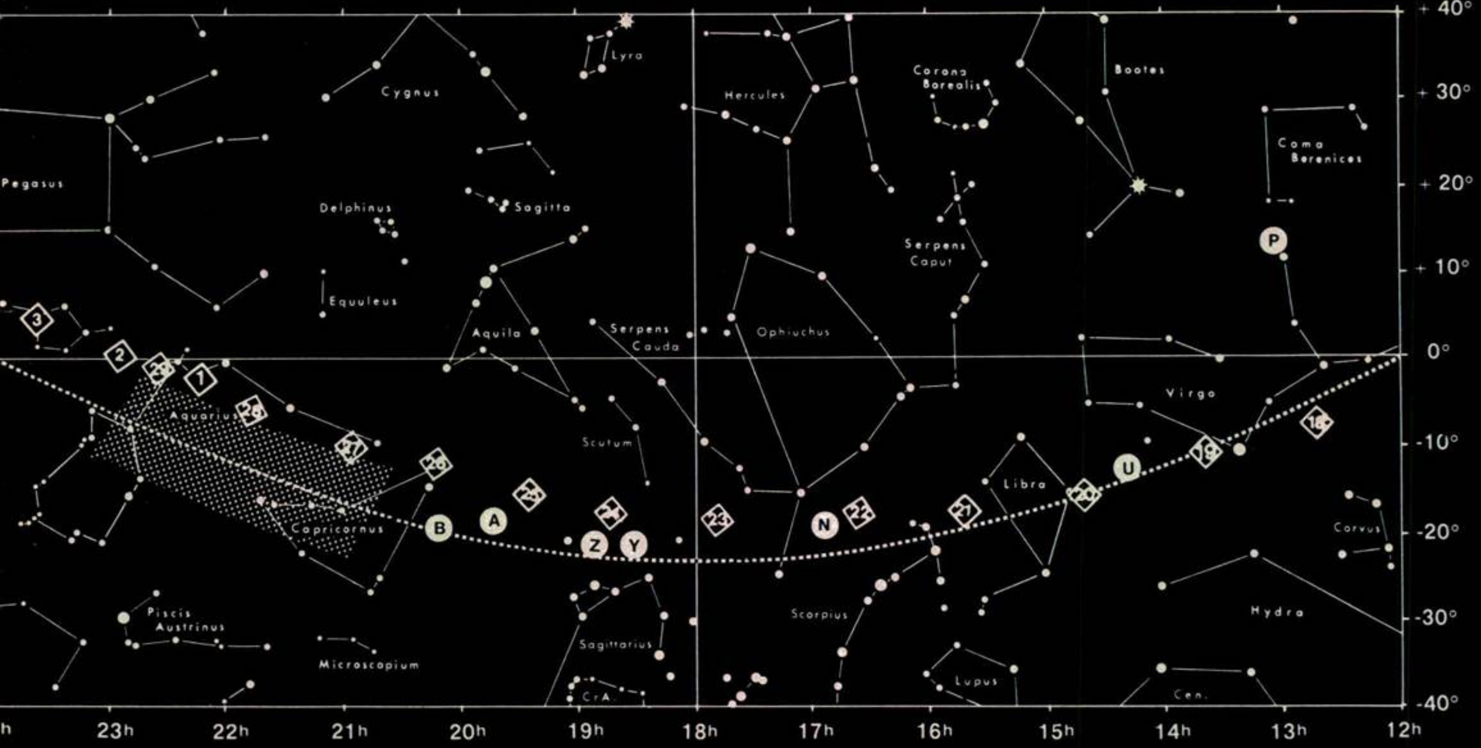
Full Moon

Feb. 15



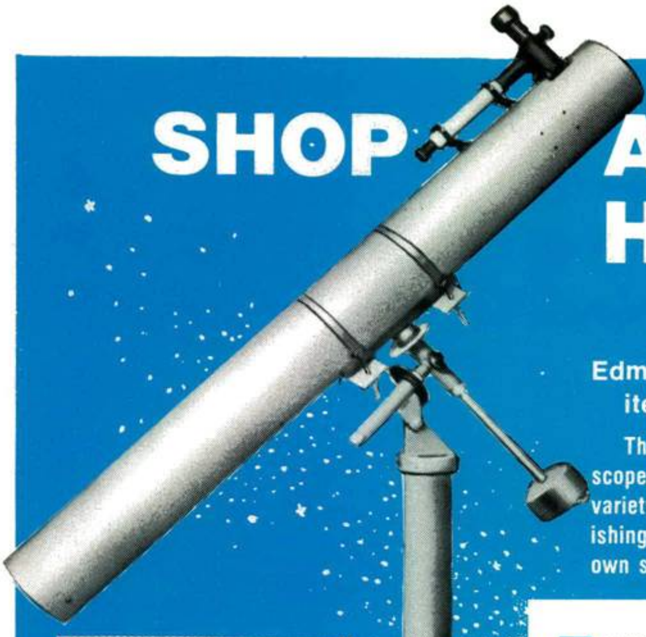
Last Quarter

Feb. 22



Pegasus
Cygnus
Lyra
Hercules
Corona Borealis
Bootes
Coma Berenices
Delphinus
Sagitta
Serpens Caput
Equuleus
Aquila
Serpens Cauda
Ophiuchus
Virgo
Aquarius
Scutum
Libra
Capricornus
Corvus
Piscis Austrinus
Microscapium
Sagittarius
Scorpius
Hydra
Lupus
CrA
Cen.
3
2
29
1
28
27
26
25
24
23
22
21
20
19
18
B
A
Z
Y
N
U
P
+40°
+30°
+20°
+10°
0°
-10°
-20°
-30°
-40°
h
23h
22h
21h
20h
19h
18h
17h
16h
15h
14h
13h
12h

measurement of the object's brightness. (The minus magnitudes indicate very bright planets.) The diamonds with numbers within them indicate the position of the moon for each day of the month; the numbers correspond to the dates. Positions of the planets are for the 15th of the month except for Mercury and Venus which are shown on both the 1st and 15th. Certain areas of this map and the Star Dome chart overlap each month.



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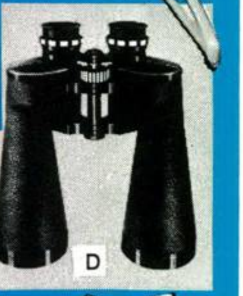

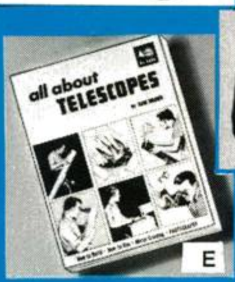

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6-INCH RV-6
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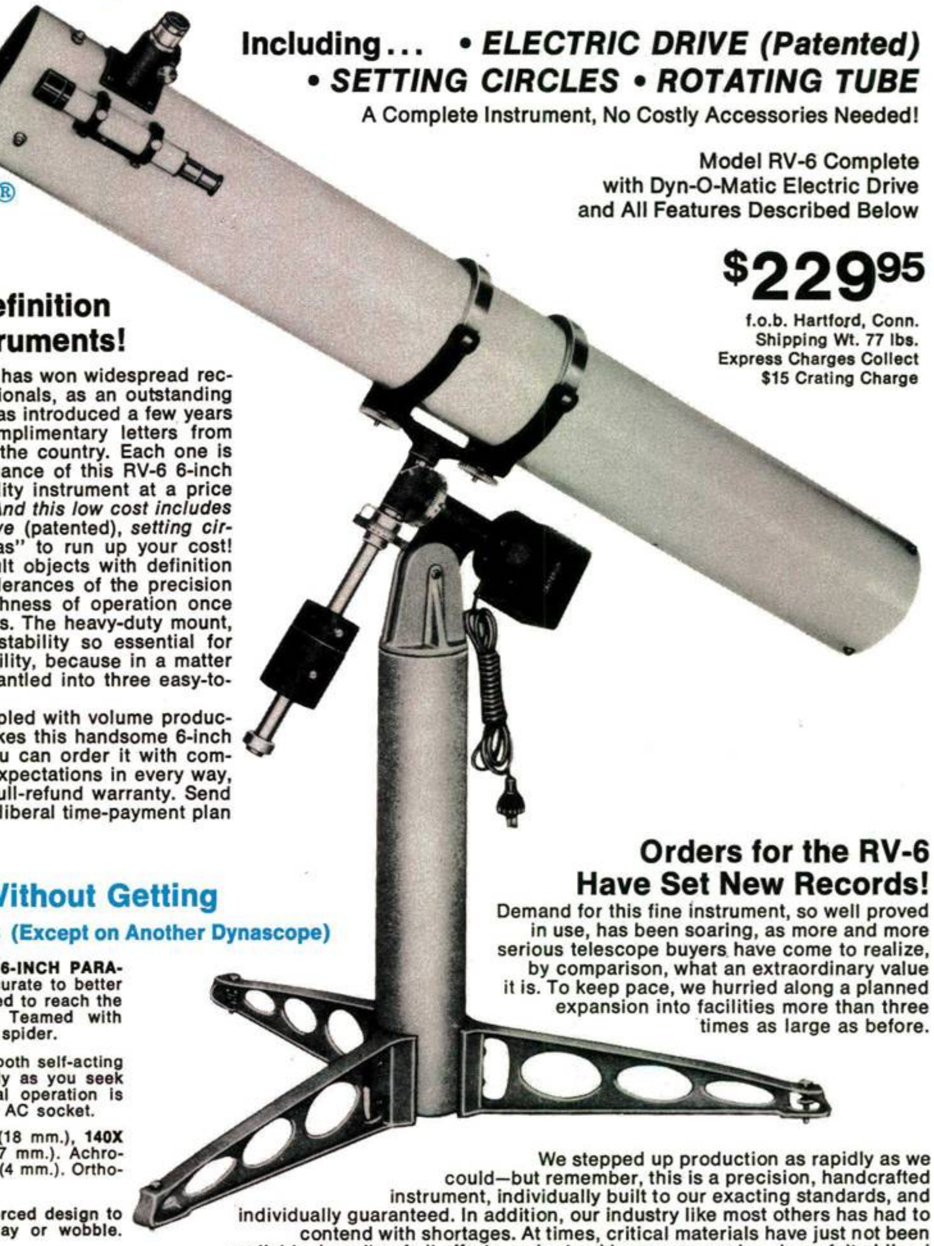

**Including... • *ELECTRIC DRIVE (Patented)*
• *SETTING CIRCLES* • *ROTATING TUBE***

A Complete Instrument, No Costly Accessories Needed!

Model RV-6 Complete
with Dyn-O-Matic Electric Drive
and All Features Described Below

$229.95

f.o.b. Hartford, Conn.
Shipping Wt. 77 lbs.
Express Charges Collect
$15 Crating Charge

Give The Same Exquisite Definition As Far More Expensive Instruments!

This staunch leader of the Dynascope line has won widespread recognition from schools, colleges, and professionals, as an outstanding achievement in a 6-inch telescope. Since it was introduced a few years ago, our files have become filled with complimentary letters from excited amateurs and professionals all over the country. Each one is truly amazed at the superior optical performance of this RV-6 6-inch Dynascope! Here is large aperture in a quality instrument at a price that compares with many 4-inch telescopes. *And this low cost includes such exclusive extra features as electric drive* (patented), *setting circles, and rotating tube!* There are no "extras" to run up your cost!

The superb optical system resolves difficult objects with definition that is absolutely breathtaking. The close tolerances of the precision construction assure an accuracy and smoothness of operation once associated only with the finest custom models. The heavy-duty mount, complete with electric drive, provides the stability so essential for satisfactory viewing, yet there is easy portability, because in a matter of minutes the entire telescope can be dismantled into three easy-to-handle sections.

Only Criterion's engineering ingenuity, coupled with volume production and modern manufacturing methods, makes this handsome 6-inch model available at such reasonable cost. You can order it with complete confidence that it will live up to your expectations in every way, for this assurance is *guaranteed* under our full-refund warranty. Send your check or money order today. Or use our liberal time-payment plan and take months to pay.

You Could Pay $100 More Without Getting All These Superior Features (Except on Another Dynascope)

1. **EXQUISITE OPTICAL SYSTEM INCLUDES f/8 6-INCH PARABOLIC MIRROR** made of **PYREX**-brand glass, accurate to better than 1/8 wave, zircon-quartz coated, and guaranteed to reach the theoretical limits of resolution and definition. Teamed with elliptical diagonal mounted in 4-vane adjustable spider.

2. **NEW DYN-O-MATIC ELECTRIC DRIVE** with smooth self-acting clutch that engages and disengages automatically as you seek different objects. Will not interfere when manual operation is desired. Safety housed case. Plugs into ordinary AC socket.

3. **TWO EYEPIECES:** Achromatic Ramsdens **70X** (18 mm.), **140X** (9 mm.). Also available: **100X** (12.7 mm.), **180X** (7 mm.). Achromatic Ramsdens, $14.95 each; **220X** (6 mm.), **320X** (4 mm.). Orthoscopics, $18.50 each.

4. **SOLID NEW EQUATORIAL MOUNT,** extra-reinforced design to provide pillarlike stability. No annoying side play or wobble. Adjusts easily to any latitude.

5. **SETTING CIRCLES** for both right ascension and declination. Handsomely engraved and finished in fine aluminum.

6. **6 x 30 FINDERSCOPE, ACHROMATIC, COATED,** with accurate cross hairs and fine focus. Durable cast-aluminum bracket with 6 adjusting screws allows positive collimation.

7. **ROTATING TUBE FOR MAXIMUM VERSATILITY AND VIEWING COMFORT.** Solid-cast chrome-finished rings are generous 1″ wide with felt lining. Newly designed construction, with oversized knurled adjusting knobs, affords maximum rigidity and allows quick disassembly and portability, with or without tube.

8. **STRIKINGLY HANDSOME WHITE 50″ BAKELITE TUBE** with porcelainized Duralite finish, durable yet light. Walls are 1/8″ thick, completely insulated and anti-reflective blackened inside.

9. **BRASS RACK-AND-PINION EYEPIECE HOLDER** has precision-cut rack and gear for easier, smoother, more positive focusing. Takes standard 1¼″ oculars, negative or positive.

10. **STRONG, VIBRATION-FREE, ALL-METAL TRIPOD** with easily removable legs. Provides sure, steady support, plus lightweight portability.

Orders for the RV-6 Have Set New Records!

Demand for this fine instrument, so well proved in use, has been soaring, as more and more serious telescope buyers have come to realize, by comparison, what an extraordinary value it is. To keep pace, we hurried along a planned expansion into facilities more than three times as large as before.

We stepped up production as rapidly as we could—but remember, this is a precision, handcrafted instrument, individually built to our exacting standards, and individually guaranteed. In addition, our industry like most others has had to contend with shortages. At times, critical materials have just not been available. In spite of all efforts, order backlogs grew, and we have felt obliged to offer refunds to anyone who did not want to wait. (Very few accepted—which itself is significant.) Today our backlog has been brought down a great deal, though we must still reluctantly keep you waiting a while. Our apologies... but it is comforting to know that when your telescope arrives, it will be in every respect the easy-to-operate, outstanding performer you ordered—an RV-6 Dynascope.

Criterion Manufacturing Co.

620 Oakwood Ave., West Hartford, Conn. 06110
Manufacturers of Quality Optical Instruments

Criterion Manufacturing Co. Dept. AS-39
620 Oakwood Ave., West Hartford, Conn. 06110

☐ Please send me, under your unconditional guarantee, the RV-6 6-inch Dynascope. Payment of $229.95 plus $15.00 crating charge is enclosed.

☐ Send FREE ILLUSTRATED LITERATURE describing the RV-6 6-inch Dynascope and all the telescopes in the Dynascope line.

☐ Send FREE ILLUSTRATED LITERATURE on your new DYNA-TRACKER™ Variable-Speed Control for RV-6 or other electric-drive telescopes.

Name

Address

City State Zip

Presenting the $595 Celestron 5

Effective immediately, for an indefinite period of time, the base price of the Celestron 5 is reduced from $750 to $595.

It's still the same Celestron 5 — famous the world over for its brilliant, razor-sharp images — famous the world over for its compact portability, elegant simplicity of operation and incredible versatility.

It's still the same telescope selected by serious amateur astronomers, and by professional astronomers for use as a personal portable — the same telescope selected by science centers for research projects and by casual observers for nature studies.

It weighs 12 pounds, swings down to 7 x 8 x 16 inches and has a useful magnification range of 30 - 300X.

It will show you the polar caps of Mars, the remarkable rings of Saturn, the ever-changing belt structure of Jupiter or the eerie filamentary glow of the Great Orion Nebula just as plainly as it'll show you the dust on a piece of thread at 100 feet.

For terrestrial photography, convenient photographic adaptors let you couple your 35mm SLR in seconds, and the 4-pound tube even demounts for hand-held shots at 25X. For astrophotography, other accessories make planetary photography a snap, or convert the instrument into a deep-sky camera that produces glorious color portraits in minutes.

In a word, it's still the same Celestron 5. Nothing's changed about it.

Except the price.

So act now; send for your free color catalog.

Because a buy like this comes along once in a blue moon.

The Celestron 5,
with star-locating circles
and electric star tracker, set up
for tabletop astronomy.

Celestron 5 Photo

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